Individual differences in temporal selective attention

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ISBN hardcopy: 978-90-367-8587-7
ISBN e-book: 978-90-367-8586-0

Design: Ellen Beck, www.ellenbeck.nl

This research was supported by a grant of the Behavioural and Cognitive Neurosciences (BCN) Research School. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of any of the chapters presented in this thesis.

rijksuniversiteit
groningen

Individual differences in temporal selective attention

Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. dr. E. Sterken
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op

woensdag 24 februari 2016 om 14.30 uur

door

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geboren op 21 maart 1989
te Zwolle

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"WE TAKE A HANDFUL OF SAND FROM THE ENDLESS LANDSCAPE OF AWARENESS AROUND US AND CALL THAT HANDFUL OF SAND THE WORLD"

Robert M. Pirsig,
Zen and the Art of Motorcycle Maintenance: An Inquiry Into Values

[*] *Individual differences in the attentional blink*

[**] *Training and the attentional blink*

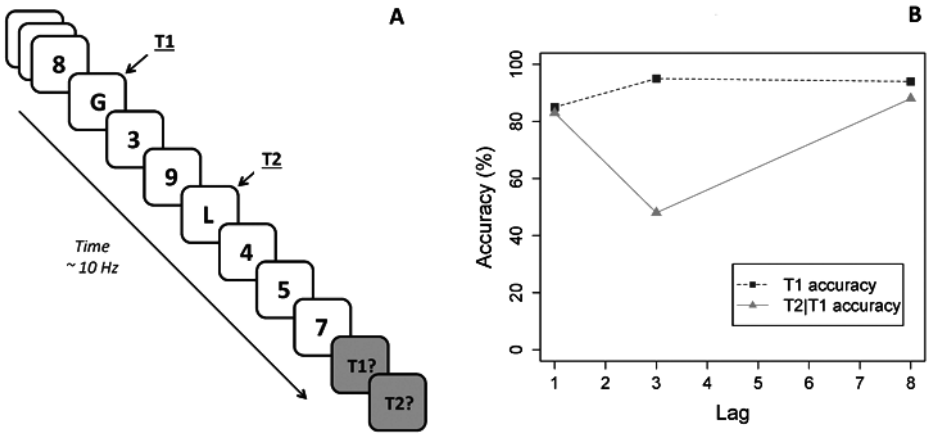
INHOUD

GENERAL INTRODUCTION: THE ATTENTIONAL BLINK

In our ever-changing world, our visual system is continuously bombarded with information that all has the potential of being important. But seemingly effortlessly, we cope with this dynamic input by constantly estimating the relevance of incoming information. Whereas relevant information is processed up to conscious awareness, irrelevant information is discarded as soon as it is no longer needed. This implies that all information that eventually reaches conscious awareness is selected by our attentional system in either space or time. In case of the latter, it regards temporal selective attention, and the workings of this system will be the topic of this thesis.

To study the workings of temporal selective attention, the attentional blink paradigm has proven to be suitable (Raymond, Shapiro, & Arnell, 1992). In this paradigm, as depicted in Figure 1.1A, a rapid stream of visual stimuli is sequentially presented in the middle of a screen at a rate of about 10 stimuli per second. Typically, the rapid serial visual presentation (RSVP) stream consists of two to-be-identified target stimuli (e.g., letters) embedded in a series of distractor stimuli (e.g., digits), and at the end of the stream, participants are asked to report the two targets. As can be seen in Figure 1.1B, correct report of the first target stimulus (T1) is often at ceiling, whereas report of the

Figure 1.1. A) The design and B) the results of a typical AB task.



second target stimulus (T2) fails frequently when T2 is presented in close temporal succession of T1 (200-500 ms). However, if T2 is presented either directly or after a longer time period following T1, identification of T2 is often successful. Furthermore, accurate report of T2 is not problematic when people are instructed to ignore T1, which shows that missing T2 must be due to attentional restrictions rather than perceptual limitations. Therefore, by analogy with an eye blink, this short period of difficulty to identify T2 following T1 identification was named the attentional blink (AB; for reviews see: Dux & Marois, 2009; Martens & Wyble, 2010).

CAPACITY LIMITATIONS VS. ATTENTIONAL STRATEGY

Studying the AB can inform us about how we select and process information in time, as well as about working memory (WM) and conscious awareness. However, despite over two decades of research, the exact nature of the AB remains unclear. Earlier studies have pointed to a role of attentional capacity limitations, theorizing that the cognitive resources available may not be sufficient to process information up to conscious awareness at such a fast rate (e.g., Chun & Potter, 1995; Dell'Acqua, Dux, Wyble, & Jolicœur, 2012; Shapiro, Raymond, & Arnell, 1994). However, recently, it is mostly argued that the AB is at least partly due to the default use of an attentional strategy (e.g., Di Lollo, Kawahara, Shahab Ghorashi, & Enns, 2005; Nieuwenstein & Potter, 2006; Olivers, van der Stigchel, & Hulleman, 2007; Taatgen, Juvina, Schipper, Borst, & Martens, 2009; Wyble, Bowman, & Nieuwenstein, 2009). That is, paradoxically with regard to resource limitations, it has been shown that AB task performance can be enhanced by increasing attentional work load, for example by listening to music, thinking about task-irrelevant topics, or performing an extra task next to the AB task (e.g., Arend, Johnston, & Shapiro, 2006; Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009; Thomson, Ralph, Besner, & Smilek, 2014). Furthermore, it has been found that AB task performance can be manipulated by changing task instructions (Ferlazzo et al., 2007; Nieuwenstein & Potter, 2006), and can be trained (Choi, Chang, Shibata, Sasaki, & Watanabe, 2012; Green & Bavelier, 2003). These results imply that a change in attentional strategy - possibly including relocation management of attentional resources - can influence AB task performance.

There exist various theories and models about the attentional strategy assumed to underlie the AB, of which, here, a few will be discussed shortly. For example, according to the threaded cognition model, the AB is due to overinvestment of attention to T1 processing, with T2 processing being postponed to protect T1 consolidation (Taatgen et al., 2009). It is argued that broadening of attentional focus, e.g., induced by additional task load, may alleviate attentional control allocated to T1, resulting in identification of T2. In addition, in the boost and bounce model, attentional selection functions as a filter that causes irrelevant information to be suppressed, while relevant information is boosted (Olivers & Meeter, 2008). In the AB task, T2 is accidentally suppressed, because the distractor following T1 was boosted. Here, increased task load is suggested to weaken inhibitory responses, because attention is distributed over multiple sources. Moreover, in the episodic simultaneous type serial token (eSTST) model, it has been suggested that the AB originates from a mechanism that provides

episodic distinctiveness between WM representations (Wyble et al., 2009). Here, T2 is missed, because the items following T1 are suppressed to prevent interference between WM representations. However, there are also studies that subscribe the AB to the inability to suppress distractor stimuli, suggested to cause interference between representations of T2 and neighboring distractor stimuli (e.g., Dux & Marois, 2008; Martens & Valchev, 2009). Thus, given that these and other models all provide reasonable explanations that fit experimental findings, it may be clear that the origin of the AB remains in need of further research.

INDIVIDUAL DIFFERENCES

One approach to investigate the origin of the AB consists of studying individual differences in AB task performance. That is, in spite of the assumption that the AB is robust and universal, there are large individual differences in AB task performance (Dale & Arnell, 2013; Dale, Dux, & Arnell, 2013). In addition to sample means, studying individual differences within a sample can outline a more complete picture of temporal selective attention. In order to establish what is currently known about individual differences in the AB, in chapter 2 of this thesis, we reviewed the literature in this field as published up to August 2015. Here, we sketch the role of both executive functioning of working memory (WM) and the span of attentional focus as predictors of individual AB magnitude.

To further investigate the origin of differences in individual AB magnitude, in chapter 3, we address individual AB magnitude in relation to three dimensions of temporal selective attention as proposed by Vul, Nieuwenstein, & Kanwisher (2008); by analyzing erroneous target reports, we studied whether there are individual differences in suppression of surrounding distractor stimuli, i.e., efficacy, and in delay and diffusion of attention in time, i.e., latency and precision, respectively. Moreover, we investigated patterns of intrusion errors and reversed order reports in relation to individual AB magnitude. In chapter 4, we elaborate on these reversed order reports and earlier work of Akyürek et al. (2012) by examining the relation between individual AB task performance, reversed order reports, and the tendency of people to temporally integrate information into one visual event. In other words, we investigated the relation between AB magnitude and preservation of timing regarding incoming information.

PUPIL DILATION

To collect more information about the timing and amount of attention allocated to the stimuli in the AB task at a neurophysiological level, pupil dilation - assumed to reflect attentional effort - can be measured (Hess & Polt, 1960; Hoeks & Levelt, 1993; Kahneman & Beatty, 1966). However, because the response of the pupil takes approximately 1 sec, pupil responses to a rapid stream of stimuli at a rate of 10 Hz result in overlapping signals. By using the pupil dilation deconvolution method (Wierda, van Rijn, Taatgen, & Martens, 2012), one can isolate the pupil responses associated with the targets in the AB paradigm, and hereby, estimate when and how much attention is invested in target processing. With the deconvolution method, we investigated attentional patterns related to individual differences in AB magnitude by means of pupil dilation, as is described in chapter 5. Here, we address both timing and investment of attentional allocation as potential predictors of individual differences in AB task performance.

TRAINING OF PERFORMANCE

As AB task performance varies between individuals, it can also change within individuals, which is most obvious after individuals are trained to improve task performance. Recently, it has been shown that the AB can be resolved by only a short training, containing a color-salient T2 and consistent time interval between the targets (Choi et al., 2012). Earlier, it has already been shown that the AB can be attenuated, e.g., by practicing video gaming or meditation (Green & Bavelier, 2003; Slagter et al., 2007). However, for over two decades, it had been assumed that the AB could not be trained away (Braun, 1998; Taatgen et al., 2009).

In the 6th chapter of this thesis, we aimed to replicate the color-salient training effect, and to extend this result by measuring pupil dilation both pre-training and post-training. Here, it will also be discussed whether the effect of the color-salient training might be due to the consistent time interval between the targets, i.e., that temporal expectations are raised regarding the target positions in the stream (Tang, Badcock, & Visser, 2013). Questioning the temporal expectations hypothesis, though, in chapter 7, we present a new non-RSVP training paradigm with trials consisting of only one letter stimulus masked by a digit stimulus. To test the robustness of the expected target-mask training effect, we re-tested participants on the AB task about one month after the training session. Again, we measured pre- and post-training pupil dilation to reveal the effect of the target-mask training on attentional allocation in the AB task. Finally, in the last chapter of this thesis, all previously mentioned chapters will be shortly summarized, and discussed in relation to the literature.

To summarize, in this thesis I will address the characteristics of temporal selective attention related to both individual AB task performance and training-induced changes in AB task performance, using pupil dilation to map associated patterns of attentional allocation. Moreover, implications of these results will be discussed regarding the nature of the AB.

Charlotte Willems and Sander Martens

TIME TO SEE THE BIGGER PICTURE

This chapter has been published in Psychonomic Bulletin & Review, 2015.

ABSTRACT

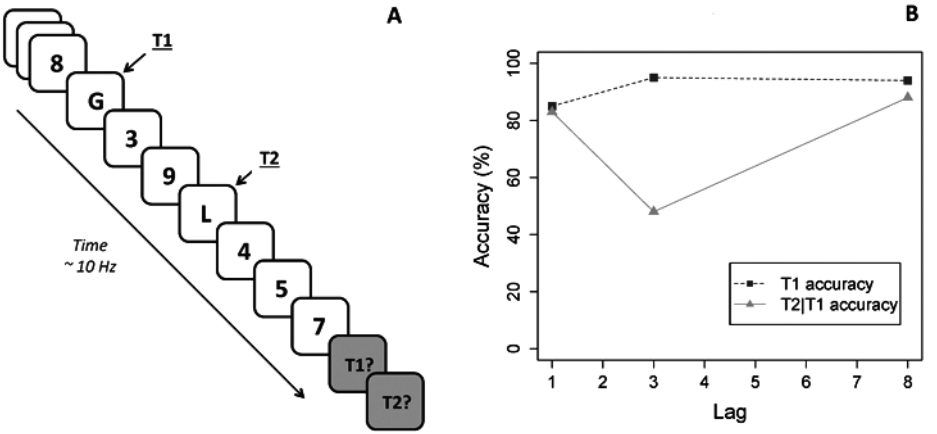
If two to-be-identified targets are presented in close temporal succession, identification for the second target is typically impaired. This attentional blink (AB) phenomenon has long been considered as a robust, universal cognitive limitation. However, more recent studies have demonstrated that AB task performance greatly differs between individuals, with some individuals even showing no AB in certain paradigms. Several studies have focused on these individual differences in an attempt to reveal the mechanism underlying the AB, but an overview of this approach is currently missing.

Here, by reviewing studies regarding individual differences in AB task performance, we investigate how individual differences have contributed to our understanding of the AB. We show that the individual differences AB literature provides reliable indications that the AB is a multifaceted phenomenon that presumably arises from a combination of factors; individuals with higher levels of executive working memory (WM) functioning and broad attentional focus perform better in the AB paradigm than individuals with lower executive functioning of WM and narrow attentional focus. As it turns out, seeing the bigger picture certainly seems helpful for AB task performance.

THE ATTENTIONAL BLINK: AN INDIVIDUAL DIFFERENCES APPROACH

Every waking moment, we are surrounded by an overload of visual information that is nowadays only increasing as a result of modern technology. To deal with this information, selective attention plays a crucial role in assuring that attention is allocated to relevant information instead of irrelevant information, e.g., to a traffic sign instead of a commercial billboard. This system works well when one piece of information, i.e., a single target, has to be identified. However, temporal selective attention starts to fail when a second to-be-identified target is presented in close temporal succession of the first target. This cognitive limitation is called the attentional blink (AB; Raymond et al., 1992), and its origin can be systematically studied with the AB paradigm, revealing the cognitive processes that underlie selection and consolidation of information in the temporal dimension. Here, as depicted in Figure 2.1A, two target stimuli embedded in a Rapid Serial Visual Presentation (RSVP) stream of distractor stimuli (~10 Hz) have to be identified, and reported after the stream ends. Typically, as shown in Figure 2.1B, first target (T1) accuracy is close to ceiling, but when the second target (T2) follows the first one in close temporal proximity (200-500 ms), the rate of accurate T2 reports drops dras-

Figure 2.1. A) The design and B) the results of a typical AB task.



tically. In case no intervening distractors are presented between the two targets, or the lag between T1 and T2 increases, T2 accuracy approaches T1 accuracy (for reviews see: Dux & Marois, 2009; MacLean & Arnell, 2012; Martens & Wyble, 2010). By virtue of the fact that the AB occurs on some trials, but not on others with identical sensory input, both failures and successes of temporal selective attention, working memory (WM), and conscious awareness can be compared.

The source of the AB has been widely debated over the last twenty years. Whereas earlier studies have focused on a role of resource depletion (e.g., Chun & Potter, 1995), more recently, evidence has been revealed that the AB may at least partly result from adverse attentional strategies (e.g., Di Lollo, Kawahara, Shahab Ghorashi, & Enns, 2005; Nieuwenstein, Chun, Van der Lubbe, & Hooge, 2005; Olivers & Nieuwenhuis, 2005, 2006; Taatgen, Juvina, Schipper, Borst, & Martens, 2009; Wierda, van Rijn, Taatgen, & Martens, 2010; Wyble, Bowman, & Nieuwenstein, 2009). That is, although there is evidence for a role of capacity limitations of short-term WM (Chun & Potter, 1995; Dell'Acqua et al., 2012; Duncan, Ward, & Shapiro, 1994), it has been shown that AB task performance can be enhanced through either manipulation (Arend et al., 2006; Ferlazzo et al., 2007; Nieuwenstein & Potter, 2006; Olivers & Nieuwenhuis, 2006; Taatgen et al., 2009; Wierda et al., 2010) or training (Choi et al., 2012; Oei & Patterson, 2013; Reedijk, Bolders, Colzato, & Hommel, 2015; Tang et al., 2013; Willems, Damsma, Wierda, Taatgen, & Martens, 2015). This suggests that changing attentional strategies can alter AB task performance, perhaps comprising faster processing or the relocation of attentional resources.

One approach to further investigate the nature of the AB is to study individual differences. Although the AB phenomenon has long been considered to be a fundamental, universal limitation, large individual differences exist in AB task

performance (e.g., Dale & Arnell, 2010; Feinstein, Stein, Castillo, & Paulus, 2004; Martens, Munneke, Smid, & Johnson, 2006; McLaughlin, Shore, & Klein, 2001). Under certain task conditions, there are even individuals—sometimes referred to as non-blinkers—who show little or no AB (e.g., Feinstein et al., 2004; Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013). Studying the variability of AB magnitudes throughout the population can help to construct a more complete and detailed picture of the dynamics of temporal selective attention. To this end, in the last fifteen years, a substantial body of research has focused on individual differences in AB magnitude, disclosing important clues regarding the nature of the AB. However, in spite of multiple reviews written about the AB phenomenon in general (Dux & Marois, 2009; Hommel et al., 2006; MacLean & Arnell, 2012; Martens & Wyble, 2010), an overview of studies regarding individual differences is currently missing in the literature. Therefore, by providing such an overview, here, we will reveal the state of the art in the individual differences AB literature. First, we will address the reliability of individual AB task performance within an AB task, between different AB tasks and related tasks, and as a function of time. Second, we aim to reveal the origin of individual AB task performance, where we will focus on indications regarding the adverse attentional strategy that is said to underlie the AB.

METHODS

Two different databases with peer-reviewed literature, i.e., PubMed and PsycINFO, were searched with the search strings as presented in Table 2.1. The last search was performed on August 18th, 2015, and papers were included according to the following criteria: 1) The study concerns the AB paradigm as used to measure the dynamics of temporal selective attention. 2) The study concerns healthy participants. 3) The study investigates differences between individuals regarding AB task performance, or investigates the relationship between individual AB task performance and other factors. This resulted in the inclusion of 68 papers, marked with a "*" in the reference list and summarized in Table 2.2, included as supplementary information (SI).

Throughout the selected papers, different statistical techniques have been employed to analyze the data, which is indicated per study in Table 2.2 (see SI). Although a detailed discussion of the statistical approach of these studies lies outside the scope of this review, it should be noted that the splitting of continuous data into (extreme) groups and possible additional dichotomization is accompanied with certain costs, including inflated effect sizes and p-values (MacCallum, Zhang, Preacher, & Rucker, 2002; Preacher, Rucker, MacCallum, & Nicewander, 2005). Although such studies can certainly be meaningful, these results should be interpreted with caution. Furthermore, these results need to be replicated in future studies employing a continuous approach of the data. That is, the disadvantages of splitting continuous data are in potential averted when analyzing the sample as a continuum whenever possible, where the use of generalized linear mixed models is preferred over repeated measures analyses of variance (Baayen, Davidson, & Bates, 2008; Bolker et al., 2009).

Table 2.1. The search strings as used to search the selected databases.

DATABASE	SEARCH STRING
PsycINFO	(DE "Attentional Blink" OR TX (attention* AND (blink* OR nonblink*))) AND (DE "Individual Differences" OR TX (individual* OR develop* OR magnitud*))
PubMed	("Attentional Blink"[Mesh] OR (attention*[tw] AND (blink*[tw] OR nonblink*[tw]))) AND ("Individuality"[Mesh] OR individual*[tw] OR development*[tw] OR magnitud*[tw])

RELIABILITY OF INDIVIDUAL AB TASK PERFORMANCE

INDIVIDUAL AB MAGNITUDE WITHIN TASKS

Although methods have been proposed that can either attenuate (Arend et al., 2006; Oei & Patterson, 2013; Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009; Wierda et al., 2010), or resolve the AB (Choi et al., 2012; Reedijk et al., 2015), it is generally found that individual AB magnitude cannot be reduced by simply practicing the task (Braun, 1998). Evidence for this was also provided in Dale and Arnell (2013), and Dale, Dux, and Arnell (2013), where the internal-consistency reliability was tested within different variations of the AB paradigm that are common in the literature. Using a split-half procedure, performance within tasks was found to correlate reasonably high; Spearman-Brown corrected *r* ranged from .48 to .91, and .54 to .76 in Dale and Arnell (2013), and Dale et al. (2013), respectively. Further evidence for the reliability of individual performance within tasks was inter alia revealed in Martens and Johnson (2009), and Martens and Valchev (2009), where Spearman-Brown prophecy coefficients were > .84 for AB magnitude, > .83 for T1 accuracy, and > .91 for T2 accuracy given correct report of T1, i.e., T2 | T1.

INDIVIDUAL AB MAGNITUDE ACROSS TASKS

Individual AB task performance has also been found to be reliable between tasks. To the best of our knowledge, the first evidence that individual AB task performance is stable between an AB task and an AB-like task was reported by McLaughlin et al. (2001). They found a positive relationship between individual AB task performance and performance on a so-called attentional dwell time task (Duncan et al., 1994), in which participants had to identify two masked targets with varying lags between the two targets, i.e., lacking the typical distractor stimuli of the AB paradigm. Note however that individual AB magnitude has been found to differ dependent on task conditions such as stimulus category and duration, or the modality in which the RSVP is presented (Heinz et al., 2007; Martens, Dun, Wyble, & Potter, 2010; Martens, Johnson, Bolle, & Borst, 2009; Martens, Wierda, Dun, de Vries, & Smid, 2015; Martens, Kandula, & Duncan, 2010; Martens, Korucuoglu, Smid, & Nieuwenstein, 2010; Willems, Wierda, Viegen, & Martens, 2013). For example, it was found that individuals who showed no AB when target selection could be based on alphanumerical information did show a drop in T2 accuracy when the RSVP contained picture stimuli, T1 was rotated, or when targets had to be identified based on color (Martens, Dun, et al., 2010; Martens, Korucuo-

glu, et al., 2010; Willems et al., 2013). Despite these findings, intra-individual differences between AB tasks as used throughout the literature are assumed to be stable; Dale et al. (2013), and Kelly and Dux (2011) showed reasonably high correlations between intra-individual performance in AB paradigms in which target selection had to be based on either category or feature information ($r > .43$). Furthermore, they compared AB tasks containing similar instructions for T1 and T2 detection with AB tasks containing a task-switch between T1 and T2 detection, e.g., "Identify the letter in a stream of digits (T1), and determine whether this letter was followed by a white X (T2)". Relations between performance on a task with task-switch and performance on a task without task-switch were found to be reliable ($r > .21$) (Dale & Arnell, 2013; Dale et al., 2013, but see: Kelly & Dux, 2011, who failed to find such a relationship), although intra-individual performances on two tasks without task-switch were stronger related. Dale and colleagues concluded that in spite of shared variability in the task-switch vs. no task-switch comparison, inclusion of a task-switch does introduce variability that is unrelated to the AB.

INDIVIDUAL AB MAGNITUDE OVER TIME

Performance thus seems to be fairly stable within the timespan of one experimental session, but what about a longer time span? Dale and Arnell (2013), and Dale et al. (2013) reported that individual AB task performance was stable over a time period of 7-10 days ($r > .39$). However, throughout the course of life, changes can be observed in the pattern of individual AB task performance. Because the temporal selective attention system is still developing during childhood, children under the age of 10 do not yet show the typical hook-shaped pattern as seen in adults (Garrad-Cole, Shapiro, & Thierry, 2011; Heim, Benasich, Wirth, & Keil, 2013; Heim, Wirth, & Keil, 2011). Instead, young children show the largest dip in performance at lag 1, after which T2 accuracy recovers linearly. Furthermore, the slope of this recovery is smaller than commonly seen in adults. Around the age of 10-11, the more typical AB pattern emerges in the performance of children, and from this point up to adulthood, a general increase in performance is observed (Garrad-Cole et al., 2011; Heim et al., 2013, 2011).

Around the age of forty, individual AB task performance is thought to reach its peak, after which a trend of decline sets in (Georgiou-Karistianis et al., 2007). As measured in adults over the age of 60, the AB of older individuals is more pronounced and lasts longer in time (Georgiou-Karistianis et al., 2007; Jain & Kar, 2014; Lahar, Isaak, & McArthur, 2001; Maciokas & Crognale, 2003; Male, Sheppard, & Bradshaw, 2009; Shih, 2009; van Leeuwen, Müller, & Melloni, 2009). In addition, overall single-target accuracy has been found to be lower compared to younger adults (Jain & Kar, 2014; Maciokas & Crognale, 2003). According to the inhibitory deficit hypothesis (Hasher & Zacks, 1988), this decline in performance is the result of the decreased ability to inhibit irrelevant information when growing older. In the AB paradigm, this inability to ignore distracting stimuli would cause problems in target selection, which is in line with studies marking the inability to suppress distractor stimuli as a source of the AB, as will be discussed below (Dux & Marois, 2008; Martens &

Valchev, 2009; Olivers & Watson, 2006). Taken together, these studies suggest that age differences can partly explain individual differences in AB magnitude, particularly in children and older adults. In a sample of young to middle-aged adults, age differences are less likely to play a role, and individual AB task performance is therefore considered to be stable over time.

DEPLOYMENT OF ATTENTIONAL CONTROL
THE ROLE OF WORKING MEMORY

Assuming that individual differences in the AB are stable within tasks, across tasks, and over time, studying the origin of these differences can reliably inform us about the nature of the AB. To this end, studies have focused on the relation between AB magnitude and individual differences in WM, given its key role in target selection and identification. In this context, it is important to note that WM functioning is assumed to consist of storage capacity on the one hand, and executive functioning on the other hand (Baddeley, 1996).

In order to examine the role of executive WM in relation to AB magnitude, Colzato, Spapé, Pannebakker, and Hommel (2007) measured individual performance in the operation span (OSPAN) paradigm, which measures the ability of participants to remember words while internal repetition is prevented by an additional mathematics task. They revealed a negative relationship between WM operational span and AB magnitude. Moreover, this relation held after they controlled for the level of fluid intelligence, often associated with individual WM functioning. This finding was replicated by Arnell, Stokes, MacLean, and Gicante (2010), where a higher OSPAN score resulted in a smaller AB magnitude when they controlled for fluid intelligence, reading comprehension and rate, and digit span. Because these latter measures are thought to represent the static storage capacity of WM, it was hypothesized that AB task performance is likely to be influenced by the level of executive functioning of WM, but not by storage capacity of WM (Arnell et al., 2010). In line with this, Arnell and Stubitz (2010) showed that individual AB magnitude can be predicted by filtering efficiency of WM, but not by visual WM storage capacity. These results do not only confirm the role of executive WM functioning, but also suggest that the individual ability to keep irrelevant information out of WM is important for individual AB task performance. Martens and Johnson (2009), though, did not find a relation between individual AB magnitude and executive WM, measured by symmetry span and reading span. They also found no evidence for a relation between AB magnitude and short-term memory measures, thought to represent storage capacity, or between AB magnitude and fluid intelligence. Taken together, these studies consistently suggest that both storage capacity of WM, and fluid intelligence are unrelated to individual AB task performance (Arnell et al., 2010; Arnell & Stubitz, 2010; Colzato et al., 2007; Klein, Arend, Beauducel, & Shapiro, 2011; Martens & Johnson, 2009; Troche, Indermühle, & Rammsayer, 2012; Wagner, Rammsayer, Schweizer, & Troche, 2014). However, the operational component of WM can be seen as modulator of AB magnitude, such that individuals who exhibit higher levels of executive functioning show smaller AB magnitudes (Arnell et al., 2010; Arnell & Stubitz, 2010; Colzato et al., 2007, but see: Martens & Johnson, 2009). In line with this, non-blinkers have been found to

update representations in WM at a faster rate than blinkers (Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013). This was indicated by the findings of earlier latencies of the P3 component in EEG analyses, irrespective of target position or lag. Thus, these results show that the AB is not likely to be the result of a structural bottleneck in static capacity limitations, but that operational capacities of WM regarding management of incoming information are important for individual AB task performance.

These results are further confirmed by studies revealing a relation between AB magnitude and the neurotransmitter striatal dopamine (DA), which can be considered to be a key player in WM functioning. However, the direction of this relationship remains unclear. Slagter et al. (2012), who measured striatal dopamine using PET scans, showed that higher levels of striatal dopamine D2-like receptor binding, i.e., lower levels of endogenous dopamine, were related to larger AB magnitudes. In line with this, Colzato, Slagter, Spapé, and Hommel (2008) found a negative relationship between spontaneous Eye Blink Rate (sEBR) - a marker of central dopaminergic functioning - and individual AB size, such that individuals with low basal dopaminergic activity showed a larger AB. A note of criticism here may be that the latter result was based on a correlation analysis in a small sample, and should therefore be considered with caution. Especially because Slagter and Georgopoulou (2013) failed to replicate the relationship between sEBR and AB magnitude.

In contrast, concerning genetic predisposition related to the efficacy of dopaminergic neurotransmission, Colzato, Slagter, De Rover, and Hommel (2011) showed a relation between individual AB magnitude and the dopamine receptor D2 (DRD2) C957T polymorphism. This polymorphism is associated with striatal DA/D2, and was tested because the DA/D2 nigrostriatal pathway has been found to be important for executive WM (Cools, Gibbs, Miyakawa, Jagust, & D'Esposito, 2008). Colzato and colleagues showed that DRD2 C957T T/T-carriers, who are assumed to have lower levels of striatal DA/D2, displayed a smaller AB than C-allele carriers. Furthermore, AB task performance could not be related to polymorphisms associated with frontal dopamine, thought to be involved in static maintenance of information. However, Felten et al. (2013) failed to replicate the relationship between AB magnitude and the DRD2 C957T polymorphism, in spite of their large sample and attempts to rule out additional confounding factors. A final example of the complexity of this topic is illustrated by Reedijk et al. (2015), who showed that presentation of alpha-frequency binaural beats can resolve the AB, but only in individuals with low sEBR, i.e., low striatal dopamine.

An explanation for these conflicting results has been proposed by Slagter et al. (2012). Following Cools and D'Esposito (2011), they hypothesized that the relationship between the level of striatal dopamine and AB magnitude may actually be u-shaped, where either too little or too much dopamine would hurt AB task performance. However, Slagter et al. presented no evidence to support this claim. So, despite indications that dopamine, as representative of WM functioning, plays a role in accounting for individual AB task performance, the precise nature of this relationship remains a topic for future research.

INHIBITION OF IRRELEVANT INFORMATION

One way in which higher-level executive WM could benefit AB task performance is by efficient inhibition of distracting information. Indeed, as mentioned before, Arnell and Stubitz (2010) found a relation between AB magnitude and WM filtering efficiency, and the deeper and longer-lasting AB of older adults was attributed to the deteriorated ability to inhibit irrelevant information (Georgiou-Karistianis et al., 2007; Jain & Kar, 2014; Lahar et al., 2001; Maciokas & Crognale, 2003; Male et al., 2009; Shih, 2009; van Leeuwen et al., 2009).

The importance of the ability to ignore irrelevant information was also suggested by Dux and Marois (2008), who showed that sensitivity to a priming cue could predict individual AB magnitude. That is, by priming the identity of T2 with a cue presented in the RSVP, they found that the size of the AB predicted how much performance improved as a result of priming, such that large blinkers showed the largest decrease in AB magnitude when T2 was primed. This suggests that target-irrelevant information in the RSVP is better inhibited in small blinkers than in large blinkers (but see: Slagter & Georgopoulou, 2013, who suggest that the length rather than the depth of the AB can be predicted by sensitivity to priming).

In line with this, Martens and Valchev (2009) compared an attentional dwell time task containing only two targets and two masking distractors with a regular AB task, i.e., an RSVP with two masked targets embedded in distractor stimuli. They showed that whereas task performance of blinkers suffered from the extra distracting stimuli in the RSVP, performance of non-blinkers was not influenced by this manipulation. Moreover, using EEG, it was found that non-blinkers showed less distractor-related frontal activity in trials where no targets appeared than blinkers (Martens, Munneke, et al., 2006), suggesting that non-blinkers pay less attention to distractors in the RSVP than blinkers do.

A personality characteristic that is associated with efficient inhibition of irrelevant information and limitations for sustained attention is impulsiveness (Dickman, 2000). In adolescents, it was found that higher levels of impulsiveness were related to a deeper, and more protracted AB compared to lower levels of impulsiveness (Li, Chen, Lin, & Yang, 2005). Subsequently, Troche and Rammsayer (2013) made a distinction between dysfunctional impulsiveness, i.e., the tendency to act without forethought in a situation where this is disadvantageous, and functional impulsiveness, i.e., the tendency to act without forethought in a situation where this is beneficial. They found that non-blinkers scored higher on functional impulsivity, associated with higher speed of processing and more efficient processing (Dickman, 2000), but no difference was found regarding dysfunctional impulsivity. These results seem to be incompatible with those reported by Li et al. (2005), because the measuring scale used by Li et al. is thought to measure mainly dysfunctional impulsivity. Further research is therefore needed to clarify the relationship between individual AB task performance and both the level of dysfuntional impulsivity and the level of functional impulsivity.

Not directly in line with the assumption that inhibition of distractors is beneficial for AB performance is the finding that

bilingual individuals, claimed to exhibit enhanced inhibitory control, showed a more pronounced AB than monolingual individuals (Colzato, Bajo, et al., 2008; Khare, Verma, Kar, Srinivasan, & Brysbaert, 2013). However, in other cognitive tasks, Colzato, Bajo et al. (2008) found no differences in active inhibitory efficiency between bilinguals and monolinguals. Therefore, they argued that bilinguals might be better in selecting goal-relevant information when this is competing with goal-irrelevant information, because of their habit to keep two languages separate. Thus, rather than a difference in inhibitory control for the suppression of distractors, it seems that bilinguals invest more attention in processing goal-relevant information, i.e., target selection, which results in an enhanced AB in bilinguals when compared to monolinguals.

Interestingly, the suggested improved ability to ignore distractor stimuli for small blinkers does not seem to be linked to increased control over attentional capture, i.e., when a salient distractor impairs the visual search for a unique target. That is, Kawahara and Kihara (2011) did not find evidence for a relationship between AB magnitude and sensitivity to attentional capture. However, mixed results have been found with regard to habitual video game players, who are argued to exert improved control over exogenous attentional capture based on their heightened experience with visual distraction during video gaming (Cain, Prinzmetal, Shimamura, & Landau, 2014). Whereas one study showed that experienced video gamers have smaller AB magnitudes than non-video gamers (Green & Bavelier, 2003), this could not be replicated in another study (Cain et al., 2014). Furthermore, it has been shown that AB task performance can be trained by playing action video games, although not by other types of video gaming (Green & Bavelier, 2003; Oei & Patterson, 2013). Next to improved control over attentional capture, though, Oei and Patterson (2013) proposed that the enhanced AB task performance might as well be the result of improved switching of attention between items, because this is a frequently needed skill in action video gaming. Therefore, the effect of frequent video gaming on AB task performance and the role of individual differences awaits further investigation, as does the role of attentional capture.

Finally, it must be noted that the importance of distractor inhibition in the AB paradigm may be influenced by discriminability of targets among distractor stimuli. That is, Willems et al. (2013) showed that neither small blinkers nor large blinkers showed much suppression of distractor stimuli when target selection had to be based on color instead of alphanumerical information. This was confirmed by findings of Bourassa, Vachon, and Brisson (2015), who performed an EEG study with a similar letter-only RSVP. They showed that in case of an erroneous T2 report at lag 3, a P3 was detected for the distractor letter following T2. Furthermore, they showed that individuals with lower lag-3 accuracy, showed higher P3 amplitudes, and thus, responded stronger to the distractor following T2 than individuals with higher accuracy. Thus, in a paradigm with low discriminability, Bourassa et al. also found no evidence for suppressed distractors, but for delayed attentional selection. In addition, Visser and Ohan (2012) revealed that participants who are faster information processors - as indicated by a rapid automatized naming

task - have an advantage in the AB paradigm when the RSVP contained highly similar targets and distractor stimuli. However, faster processing was not found to be a predictive factor if targets and distractors were easier to distinguish. Therefore, the importance of inhibition of distractor stimuli may depend on the level of difficulty to discriminate distractors from targets, whereas processing speed may be more relevant when this distinction becomes more difficult.

SPEED OF PROCESSING

Processing speed alone, though, does not appear to be a strong determining factor for AB magnitude. However, it can be seen as predictor for the level of overall target accuracy. For example, in a sample of 8-10 year olds, overall mean T2|T1 performance was linked to normal developing reading ability (McLean, Stuart, Visser, & Castles, 2009). But whereas both general reading ability and mean T2|T1 accuracy were related to speed of processing, the level of reading ability and processing speed were not related to AB magnitude. Moreover, Arnell, Howe, Joanisse, and Klein (2006) revealed that AB magnitude could not be predicted by cognitive non-RSVP measures that require comparable information-processing abilities as the AB task, including tasks that require speeded responses. However, reaction time regarding speeded manual and vocal identification of single stimuli was related to general target accuracy in the RSVP. Therefore, speed of information processing is thought to be predictive for target accuracy, but not for individual AB magnitude per se.

TOO MUCH ATTENTION CAN HURT PERFORMANCE

Given that attentional control may help to efficiently select targets, and to ignore irrelevant information, one would expect that higher attentional investment in target identification would be beneficial for AB task performance. Paradoxically, though, it was found that adding an extra task next to the RSVP task caused performance to improve. Olivers and Nieuwenhuis (2005; 2006) showed that listening to music or thinking about holiday plans during the RSVP presentation resulted in a decreased AB magnitude (but see Footnote 1 in Olivers & Nieuwenhuis 2006, where it is noted that attempts to replicate the latter result failed or showed a substantially smaller effect). Furthermore, Wierda et al. (2010) and Taatgen et al. (2009) found that discriminating the presence of a red dot during the AB task resulted in a smaller AB magnitude. It appears that broadening of attention that is allocated to the RSVP results in better AB task performance. However, the hypothesis that loosening cognitive control by adding an extra task is beneficial for AB task performance seems to contradict with the findings that higher inhibition of distractors leads to better task performance. But where the earlier discussed inhibition of distracting information regards task-relevant distracting information in the RSVP, the distracting tasks as presented in Olivers and Nieuwenhuis (2005; 2006), Wierda et al. (2010), Taatgen et al. (2009), as well as in Arend et al. (2006) are all additional, RSVP-irrelevant tasks.

One explanation for the beneficial effect of an extra task might be that this task enforces a more shallow level of stimulus processing. More specifically, it has been suggested that participants may have a suboptimal processing strategy in which too much attention is allocated to the first target and subsequent distractors, low-

ering chances of successful report of T2 (Olivers & Nieuwenhuis, 2005, 2006; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006; Taatgen et al., 2009; Wierda et al., 2010). This overinvestment hypothesis is supported by a number of studies showing that attentional investment to T1 is higher on trials where T2 was identified incorrectly, i.e., blink trials, compared to trials where T2 was identified correctly, i.e., no-blink trials (Maclean & Arnell, 2011; Martens, Munneke, et al., 2006; Slagter et al., 2010; Wierda, van Rijn, Taatgen, & Martens, 2012).

By using magnetoencephalography, Shapiro et al. (2006) also revealed that higher attentional investment to T1 resulted in larger AB magnitudes, though it should be noted that this correlation was based on a sample of N = 10. Furthermore, Wu and Hillman (2013) found that children with higher levels of physical fitness perform better in the AB paradigm than lower fit children, in line with other studies that indicate a positive relation between psychical activity, cognitive performance, and brain health (Hillman, Erickson, & Kramer, 2008). As indicated by EEG analyses of the P3 component, it was found that higher fit children invest less attention in T1 processing during the AB period, and less attention to T2 throughout the task. Wu and Hillman argued that these results may be due to higher control over the distribution of attentional resources in case of higher aerobic fitness. In contrast, though, other studies only found a weak relationship between individual P3 amplitudes and T2 identification rate (Martens, Elmallah, London, & Johnson, 2006; McArthur, Budd, & Michie, 1999; Wagner, Rammsayer, Schweizer, & Troche, 2015). These studies show that the relation between P3 amplitude as indicator of attentional investment and individual AB task performance is definitely in need of further research (see for example Wagner et al., 2015, for ideas on future research regarding this relationship).

In support of the idea that control over attentional investment is related to AB magnitude, Dale and Arnell (2010; 2014) showed that dispositional attentional focus is related to individual AB task performance, discriminating between either a diffused attentional processing style or a focused attentional processing style. They tested individuals with the global-local task, where a large stimulus is constructed from a set of smaller stimuli, i.e., the global level and local level, respectively. These levels can either be congruent or incongruent (Navon, 1977). By using multiple variants of this global-local task, Dale and Arnell (2010; 2014) revealed that on the one hand, precedence towards a more diffused attentional style correlated negatively with the size of the AB. On the other hand, precedence towards a more focused attentional style correlated positively with AB magnitude. Moreover, it was found that large blinkers invest more in performance monitoring, which is associated with modulation of cognitive control (MacLean & Arnell, 2013). Here, large AB magnitudes were related to large electrophysiological reactions to performance feedback, indicating high investment in outcome of performance and cognitive control.

In line with this, Thomson, Ralph, Besner, and Smilek, (2014) revealed that individuals who were more frequently engaged in mind wandering showed smaller AB magnitudes, as measured with subjective reports. Interestingly, in daily life tasks (e.g., driving, reading), as well as laboratory tasks (e.g., flanker task), mind wan-

dering has been reported as detrimental for performance (Smallwood, McSpadden, & Schooler, 2008; Thomson et al., 2014). Mind wandering, assumed to result in the failure to inhibit task-irrelevant thoughts, has therefore been suggested to consume attentional resources necessary for task execution (McVay & Kane, 2011; Smallwood, 2013). This confirms the idea that - in the context of the AB - mind wandering can reduce attentional control such that it promotes a more broadly distributed rather than focused allocation of attention, and thus, enhances AB task performance.

Perhaps somewhat related to mind wandering, others found that attentional engagement during rest, i.e., when individuals are not engaged in a goal-directed task, occurred more strongly in small blinkers than in large blinkers (MacLean, Arnell, & Cote, 2012). By measuring oscillatory activity, MacLean et al. showed that activity within the alpha and beta frequency bands during resting state was predictive for the size of the AB. Whereas higher alpha activity was associated with larger AB magnitudes, higher beta-band activity was related to smaller AB magnitudes. In addition, individuals with relatively more beta- than alpha-band activity displayed a smaller AB than individuals where the ratio of alpha and beta activity was the other way around. Because alpha waves in waking state are thought to be a sign of an unoccupied cortex, MacLean et al. suggested a negative association between attentional engagement during rest and the size of the AB.

The finding that non-religious individuals displayed a smaller AB magnitude than religious people, here defined as neo-Calvinists, was also attributed to a difference in cognitive processing style (Colzato, Hommel, & Shapiro, 2010). Because Calvinism is based on a pillar concept of society where everyone minds their own business, Calvinists are thought to have a more narrow, focused processing style compared to atheists, who thus were assumed to have a broader, more diffused processing style (Colzato et al., 2010). Thus, a more open attentional processing style due to choice of religion seems to be profitable for individual AB task performance. These findings are in need of replication, however.

MacLean, Arnell, & Busseri (2010) showed that individual AB task performance is also modulated by dispositional affect, where positive dispositional affect is associated with diffused attention, and negative affect with focused attention. Measured with the Positive and Negative Affect Schedule, it was found that on the one hand, positive dispositional affect was predictive for a smaller AB magnitude, whereas on the other hand, negative affect was related to a larger AB magnitude. In addition, MacLean and Arnell (2010) showed that personality traits that are thought to be related to either positive affect or negative affect can modulate individual AB task performance. That is, greater extraversion can be seen as indicative for positive affect, and was negatively related to AB magnitude, whereas greater neuroticism - associated with negative affect - was positively related to AB magnitude. MacLean and Arnell (2010) also argued that openness to experience would result in smaller AB magnitudes, but Kranczioch and Thorne (2013) did not find any evidence for this relationship. Taken together, these studies suggest that dispositional affect and personality traits, as associated with at-

tentional focus, can be seen as modulators for AB magnitude. Finally, comparison of different meditation styles also showed the beneficial influence of broad over narrow attentional focus. In a sample of experienced meditators, Van Vugt and Slagter (2014) compared meditation where attention is focused on one point, such as an object or thought, with open monitoring (OM) meditation, which means that thoughts can come in and let go during the meditation session. They found that for very experienced meditators (mean = 10,704 hrs) the OM style was beneficial over the focused attention style when applied during the AB task. In addition, Slagter et al. (2007) showed that after an intensive training of OM meditation, participants performed better on the AB task compared to a control group. Here, individuals who showed the largest decrease in attention allocated to T1, as indicated by the T1-elicited P3b, also showed the largest improvement of AB task performance (Slagter et al., 2007). Furthermore, this decrease in attention to T1 was found to relate to a decrease of phase variability in the theta frequency band, indicating that individuals with the largest improvement in AB task performance following the meditation training were ready earlier in time to react to new target information (Slagter, Lutz, Greischar, Nieuwenhuis, & Davidson, 2009).

In line with this, Van Leeuwen et al. (2009) revealed that the age-related decline in AB task performance as seen in older adults seems to be limited if individuals acquire a substantial level of meditation throughout life. Moreover, Braboszcz et al. (2013) also found a reduction of AB magnitude as a result of meditation, testing participants before and after a three-month retreat of Isha-yoga practice, a combination of focused meditation and open monitoring. However, in contrast with these results that reveal a beneficial effect of OM meditation, Braboszcz et al. (2013) found that previous meditation experience with Shoonya yoga, a practice that can be explained either as open or as focused meditation, correlated negatively with AB task performance, such that more advanced meditators showed larger AB magnitudes. However, this latter result may be due to the difficulty of obtaining a strict separation between focused and OM meditation in experienced meditators, especially because all participants had experience with additional forms of meditation practices. Nevertheless, it can be tentatively concluded that practice of OM meditation, promoting an open attentional focus, has a beneficial effect on individual AB task performance.

DISCUSSION

In summary, individual differences in the AB paradigm have proven to be a reliable source of information regarding the nature of the AB. Furthermore, the individual differences AB literature provides indications that the AB is a multifaceted phenomenon that presumably arises from a combination of factors. First, the literature reveals that the executive component of WM can be seen as a modulator in the process of selection and consolidation of targets, where individuals with a higher operational span exhibit smaller AB magnitudes. These results are at least partly confirmed at the neurophysiological level by findings regarding the neurotransmitter striatal dopamine, serving as representative of WM functioning. These latter findings remain in need of further research, however. Furthermore, the timing and/or the rate of WM updating seem to be rel-

evant, where earlier WM updating is related to better AB task performance. One way in which higher executive functioning seems to benefit AB task performance is in the ability to keep irrelevant information out of WM, i.e., to inhibit distracting information as presented in the RSVP.

Second, the literature suggests that individual AB task performance is determined by the distribution of attention during an AB task. On the one hand, a narrow focus of attention seems to lead to attentional overinvestment to T1 identification, which subsequently causes T2 to be missed when it succeeds T1 in close temporal proximity. On the other hand, a broad focus of attention seems to provide more optimal circumstances under which both targets can be identified when these are presented in a short time frame. This focus of attention has been linked to factors as dispositional affect, personality traits, and lifestyle.

How executive WM functioning and the span of attentional focus are interlinked with regard to the AB awaits further investigation. In relation to the neural correlates of the AB, it would be particularly interesting to examine the suggestion of Slagter et al. (2012) that the relation between dopamine and AB magnitude might be U-shaped. Furthermore, with regard to these future studies, it would certainly benefit the field of individual AB differences to acknowledge and critically discuss the strengths and weaknesses of different statistical techniques applied throughout the literature.

In conclusion, the individual differences AB literature has contributed much to understanding the workings of the temporal selective attention system in the AB paradigm; individuals with higher levels of executive WM functioning, and broad attentional focus perform better in the AB paradigm than individuals with lower executive functioning of WM, and narrow attentional focus. As it turns out, seeing the bigger picture certainly seems helpful for AB task performance.

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THE TEMPORAL PROFILE OF BLINKERS AND NON-BLINKERS

This chapter has been published in PLoS ONE, 2013.

ABSTRACT

When two targets are presented in close temporal succession, the majority of people frequently fail to report the second target. This phenomenon, known as the attentional blink (AB), has been a major topic in attention research for the past twenty years because it is informative about the rate at which stimuli can be encoded into consciously accessible representations. An aspect of the AB that has long been ignored, however, is individual differences.

Here we compare a group of blinkers (who show an AB) and non-blinkers (who show little or no AB), and investigate the boundary conditions of the non-blinkers' remarkable ability. Second, we directly test the properties of temporal selection by analyzing response errors, allowing us to uncover individual differences in suppression, delay, and diffusion of selective attention across time. Thirdly, we test the hypothesis that information concerning temporal order is compromised when an AB is somehow avoided.

Surprisingly, compared to earlier studies, only a modest amount of suppression was found for blinkers. Non-blinkers showed no suppression, were more precise in selecting the second target, and made less order reversals than blinkers did. In contrast, non-blinkers made relatively more intrusions and showed a selection delay when the second target immediately followed the first target (at lag 1). The findings shed new light on the mechanisms that may underlie individual differences in selective attention. The notable ability of non-blinkers to accurately perceive targets presented in close temporal succession might be due to a relatively faster and more precise target selection process compared to large blinkers.

INTRODUCTION

Restrictions to concurrent attention and awareness are revealed by the interference that commonly results when two sensory inputs must be identified closely in time. For instance, the majority of people typically fail to report the second of two targets when presented in close temporal succession (200-500 ms) amongst a sequential stream of distractors, a phenomenon known as the attentional blink (AB; Martens & Wyble, 2010; Raymond et al., 1992).

In the past two decades, the AB has been a major topic in attention research because it is informative about the rate at which stimuli can be encoded into consciously accessible representations. Although the effect is robust and can be obtained under a variety of task conditions (Martens & Wyble, 2010), large individual differences exist in the magnitude of the effect (Arnell et al., 2006; Martens, Munneke, et al., 2006; McLaughlin et al., 2001). Such differences have long been considered as irrelevant noise,

until we demonstrated that for some individuals (referred to as 'non-blinkers') the AB can be completely absent (Martens, Munneke, et al., 2006). Given that there is currently much debate about the cause of the AB (see Dux & Marois (2009); Martens & Wyble (2010) for recent reviews), several subsequent studies have focused on individual differences in AB magnitude in an attempt to shed new light on the underlying mechanism of the AB (Arnell et al., 2010; Arnell & Stubitz, 2010; Bates, Maechler, & Bolker, 2012; Colzato et al., 2010, 2007; Colzato, Bajo, et al., 2008; Dale & Arnell, 2010; Dux & Marois, 2008; Green & Bavelier, 2003; Maclean & Arnell, 2010; Martens, Dun, et al., 2010; Martens et al., 2009; Martens & Johnson, 2009; Martens, Kandula, et al., 2010; Martens, Korucuoglu, et al., 2010; Martens, Munneke, et al., 2006; Martens & Valchev, 2009; Martens & Wyble, 2010; Shapiro et al., 2006; Slagter et al., 2007, 2010; Taatgen et al., 2009).

Representing the extreme end on a continuum of individual AB magnitudes, non-blinkers continue to show little or no AB when identification of targets is made more difficult by either increasing the overall rate of stimulus presentation (Martens, Munneke, et al., 2006) or specifically reducing the duration of the targets (Martens, Dun, et al., 2010; Martens et al., 2009; Martens, Korucuoglu, et al., 2010). In comparison to regular 'blinkers' (individuals who do show an AB), it has been found that non-blinkers neither seem to differ in short-term memory capacity, working memory (WM) capacity, nor in general intelligence level (Martens & Johnson, 2009) (but see Arnell & Stubitz, 2010; Colzato et al., 2007, which do report a relation between WM capacity and AB magnitude).

In contrast, however, EEG measurements have revealed differences in frontal and parietal brain activity, reflecting differences in target processing (Martens, Munneke, et al., 2006). In particular, more target-related activity was found over the ventrolateral prefrontal cortex (assumed to play a role in a wide range of cognitive processes, including the selection of non-spatial information), whereas blinkers showed more distractor-related prefrontal activity. Regardless of the time interval between the targets, non-blinkers were also found to be quicker in consolidating the identity of targets than blinkers, showing earlier peak latencies of the P3 ERP components - associated with the updating of working memory - induced by successfully identified targets (Martens, Munneke, et al., 2006). In line with this result, evidence was recently found that the magnitude of the AB is related to striatal dopamine functioning, which is associated with regulating the threshold for WM updating (Slagter et al., 2012). Taken together, these findings suggest that non-blinkers are more efficient in distinguishing targets from distractors at a relatively early processing stage. Indeed, behavioral studies have provided converging evidence showing that non-blinkers are better in ignoring distractors than blinkers are (Dux & Marois, 2008; Martens et al., 2009; Martens & Valchev, 2009).

It must be noted though that this early selection seems to be specific for alphanumeric, visual targets. AB magnitude was found to be similar for blinkers and non-blinkers when using pictures rather than alphanumeric stimuli (Martens, Dun, et al., 2010). Also when using auditory alphanumeric stimuli, non-blinkers showed a sub-

stantial AB effect, although overall performance was still better than that of blinkers (Martens et al., 2009).

It was therefore suggested that in an alphanumeric AB task non-blinkers might take advantage of overlearned category-level features to select targets prior to full identification, allowing them to mostly ignore distractors and to avoid an AB. Indeed, an ERP study subsequently showed that when alphanumeric category information was unavailable (only letters were presented) and target selection could only be based on information that is processed relatively late (rotation), non-blinkers again showed a substantial AB effect (Martens, Korucuoglu, et al., 2010). Delayed target-related occipital-parietal activity as well as increased distractor-related prefrontal brain activity was observed. Also, when alphanumeric category information was not available, the difference in P3 peak latency between the two groups disappeared. However, non-blinkers continued to outperform blinkers across all conditions by showing a smaller AB, suggesting that early selection processes based on category information alone cannot fully explain the observed differences between the two groups.

Nevertheless, it has been suggested that a major source of individual variability in AB magnitude must lie in processes of selective attention that are involved in determining which objects are selected for further processing and memory consolidation (Martens, Dun, et al., 2010; Martens et al., 2009; Martens & Johnson, 2009; Martens, Korucuoglu, et al., 2010; Martens, Munneke, et al., 2006; Martens & Valchev, 2009). In this regard, the insights derived from studies examining individual differences in the AB converge with recent ideas regarding the source of the AB. Whereas the earliest studies claimed that the AB is the result of capacity limitations (Chun & Potter, 1995; Shapiro et al., 1994), alternatively, the AB is lately often regarded as a problem to time or control attention (Di Lollo et al., 2005; Dux & Marois, 2009; Martens & Wyble, 2010; Taatgen et al., 2009; Wyble et al., 2009). This shift in the theoretical landscape was motivated by a number of key findings. For instance, it was found that people are capable of reporting an undisrupted stream of letters, but typically fail when required to report only a subset of this stream, as reflected in the AB task (Nieuwenstein & Potter, 2006; Olivers et al., 2007). Furthermore, it has been found that the AB is attenuated when participants perform a second task concurrently with the primary AB task (Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009; Wierda et al., 2010). Together, these studies provide evidence against theories assuming resource depletion, since according to these limited-capacity theories an additional task load should increase rather than decrease the magnitude of the AB. Given these findings, the temporal selection mechanism seems important for explaining the AB, although it must be noted that recent findings also suggest a role for capacity limitations (Dell'Acqua et al., 2012; Dell'Acqua, Jolicœur, Luria, & Pluchino, 2009; Dux, Asplund, & Marois, 2008, 2009).

The aim of the present study was to further investigate this temporal selection mechanism by contrasting the performance of blinkers and non-blinkers. In the abovementioned studies, non-blinkers showed an AB when visual target selection was based on a target-defining feature that was processed relative-

ly late, such as rotation (Martens, Korucuoglu, et al., 2010) or semantic category (Martens, Dun, et al., 2010). To test the generality of this finding, an AB experiment was set up that featured only letter stimuli with targets defined by color, a stimulus feature that is available relatively early (Rotte, Heinze, & Smid, 1997; Smid & Heinze, 1997; Wijers, 1989). This way, early target selection should be possible, and non-blinkers should still be able to avoid an AB on the majority of trials. However, if their temporal selection ability specifically relies on the presence of alphanumeric category information - which is unavailable - the occurrence of an AB is to be expected.

To study the temporal dynamics of attention in more detail, another important goal of the current study was to investigate the temporal profile of non-blinkers and blinkers using three measures of temporal selection, namely 'suppression', 'delay', and 'diffusion', originally proposed by Vul et al. (2008) and Chun (1997). Since each stimulus letter was presented only once within each stream, the serial position of any reported letter was known, thus allowing us to highlight and contrast these three dimensions of target selection in blinkers and non-blinkers (Vul, Nieuwenstein, et al., 2008). Following Vul and colleagues, if a response consists of a letter that does not correspond with any of the letters presented within a certain temporal window around a target, we assume that the relevant information was likely to be suppressed ('suppression'). If a response corresponds with a letter that was presented after a target, it can be inferred that temporal target selection was delayed ('delay'). Finally, if distractors strongly interfere with the processing of targets, selection will be less precise, reflected in selection errors that are temporally more distant from the target ('diffusion'). Vul et al. (2008) found that the temporal selection process was suppressed, delayed, and diffused during the AB.

Both the concepts of suppression and delay have previously been associated with the AB. Regarding suppression, many studies emphasized its important role during the AB (Botella, Privado, de Liaño, Suero, & Gil-Gómez de Liaño, 2011; Chun, 1997; Dux, Coltheart, & Harris, 2006; Dux & Harris, 2007; Dux & Marois, 2008; Harris, Benito, & Dux, 2010b; Kihara, Yagi, Takeda, & Kawahara, 2011; Loach & Marí-Beffa, 2003; Martens & Valchev, 2009; Olivers & Watson, 2008; Olivers, 2007; Popple & Levi, 2007; Vogel et al., 1998; Vul, Nieuwenstein, et al., 2008). In EEG studies, suppression is reflected in the P3 component that is absent or strongly attenuated during the AB (Vogel et al., 1998), and also the n2pc (associated with the allocation of attention) is known to be affected (Dell'Acqua, Sessa, Jolicœur, & Robitaille, 2006; Jolicœur, Sessa, Dell'Acqua, & Robitaille, 2006a, 2006b). Similarly there is quite some evidence supporting the idea that attentional selection is delayed during the AB, provided by behavioral studies (Botella et al., 2011; Chun & Potter, 1995; Chun, 1997; Nieuwenstein et al., 2005; Nieuwenstein, 2006; Vul, Hanus, & Kanwisher, 2008; Vul, Nieuwenstein, et al., 2008) and EEG studies (Martens, Munneke, et al., 2006; Vogel & Luck, 2002; Vogel et al., 1998), where the latter have revealed that when the second target was reported correctly at short time intervals, the P3 component was delayed in comparison to longer intervals.

Combined with our previous findings on individual differences in the AB, we predicted that non-blinkers would continue to outperform the blinkers, and would show less suppression, delay,

and diffusion. Interestingly however, although many papers suggested that information processing is suppressed during the attentional blink (e.g., Kihara et al., 2011; Olivers, 2007; Vogel et al., 1998; Vul, Nieuwenstein, et al., 2008), a number of papers have claimed that the AB is due to a failure to suppress distractor stimuli (Dux et al., 2006; Dux & Harris, 2007; Dux & Marois, 2008; Harris, Benito, & Dux, 2010a), which implies that we should find the opposite effect; individuals with little or no AB should show relatively strong suppression, whereas individuals with a large AB should show relatively little suppression.

A final prediction concerning non-blinker performance comes from a simulation study suggesting the AB to reflect a cognitive strategy of enforcing an episodic distinction between successive stimuli (Wyble et al., 2009). When the occurrence of an AB is somehow avoided, information concerning temporal order and the correct binding of features into targets might be compromised (Martens & Wyble, 2010). In other words, non-blinkers might lack the episodic distinction between successive stimuli, and subsequently make more order reversals (i.e., reporting the second target before the first target) than blinkers do. If however, non-blinkers are generally quicker to select and consolidate targets (see e.g., Martens et al., 2006), one would expect to find fewer order reversals in non-blinkers than in blinkers. A final aim was thus to test these latter predictions.

In summary, we tested whether non-blinkers can avoid an AB when targets are to be selected on the basis of color rather than alphanumeric category information. Second, we tested whether non-blinkers show less suppression, delay, and diffusion than blinkers do. And third, we investigated whether avoiding an AB comes at a cost, reflected in non-blinkers making relatively more order reversals.

METHODS

Experiment 1a consisted of an AB task with alphanumeric stimuli, requiring detection and identification of two target letters presented in a rapid serial visual presentation (RSVP) stream of 16 distractor digits. Participants were tested for the presence or absence of a sizeable AB, with the purpose of forming separate groups of consistent blinkers and non-blinkers for inclusion in Experiment 1b. Experiment 1b contained only letter stimuli, targets were defined by color, and its goal was to test the temporal profile of blinkers and non-blinkers in terms of suppression, delay, and diffusion. The purpose of Experiment 2 was to replicate the findings in a larger sample of participants.

EXPERIMENT 1A

In Experiment 1a, participants performed an AB task requiring the identification of two letter targets amongst a sequential stream of digit distractors. The purpose of this experiment was to test selected participants for the presence or absence of a sizeable AB in a classical alphanumeric AB task. In addition, we aimed to systematically study possible differences between blinkers and non-blinkers in terms of order reversals.

Participants. Twenty-nine volunteers (16 women; aged 20-31, mean = 25.0) recruited from the University of Groningen community participated in the experiment, had normal or corrected-to-normal visual acuity, normal hearing, and no history of neurological problems. One participant was excluded due to RSI problems. Thirteen participants were included because they had shown little or no AB in previous studies in our laboratory, and

were therefore regarded as potential non-blinkers. The other 15 participants had previously shown a regular to large AB, and were therefore regarded as potential blinkers. The Neuroimaging Center Institutional Review Board approved the experimental protocol and each participant signed a written consent prior to the experiment. All volunteers participated in both Experiment 1a and 1b in a single session, and received payment of € 7 in total.

Stimuli and apparatus. The generation of stimuli and the collection of responses were controlled by using E-prime 1.2 software running under Windows XP. Target stimuli consisted of uppercase consonant letters excluding 'Q', 'V', and 'Y'. Distractor stimuli consisted of digits (2 to 9). All stimuli were centrally presented in black (2 cd/m2) on a white background (88 cd/m2) in uppercase 14-point Monaco font on a 19-inch CRT monitor with a 100-Hz refresh rate. Viewing distance was approximately 50 cm.

Procedure. Each trial began with a message at the bottom of the screen, prompting participants to press the space bar to initiate the trial. When the space bar was pressed, the message disappeared immediately and a central fixation cross appeared. It remained on the screen for 100 ms, followed by the RSVP stream consisting of 18 items (i.e., 2 targets and 16 distractors).

All stimuli were presented for 80 ms without inter stimulus interval. The first target (T1) was always presented as the sixth item in the stream. The second target (T2) was the first, second, third, or eighth item following T1, and was thus presented at lag 1, 2, 3, or 8, respectively. In other words, the stimulus onset asynchrony (SOA) between the targets randomly varied from 80, 160, 240, to 640 ms. Each lag was presented equally often. Target letters were pseudo-randomly selected with the constraint that T1 and T2 were always different letters. Digit distractors were pseudo-randomly selected with the constraint that no single digit was presented twice in succession.

After the presentation of the stimulus stream, participants were prompted by a message at the bottom of the screen to indicate the letters they had seen by using the corresponding keys on the computer keyboard. Participants were instructed to take sufficient time in making their responses to ensure that typing errors were avoided. Participants were encouraged to type in their responses in the order in which the letters had been presented, but responses were accepted and counted correct in either order. Participants were instructed to guess if they had not seen the targets.

The experiment contained one practice block of 24 trials and two testing blocks of 144 trials each, and took approximately 30 minutes to complete. After the first testing block, participants were allowed to take a short break. At the end of the experiment, participants took another short break before continuing with Experiment 1b.

EXPERIMENT 1B

The purpose of Experiment 1b was twofold. First, we wanted to test whether non-blinkers continue to show little or no AB when targets are defined by color rather than alphanumeric category. To that end, all stimuli consisted of letters, with targets presented in red, and distractors in black. Second, following (Vul, Nieuwenstein, et al., 2008), we directly tested the properties of temporal selection by analyzing the distribution of reported

letters, allowing us to study the suppression, delay, and diffusion of selective attention across time in blinkers and non-blinkers.

Participants. All participants of Experiment 1a volunteered to participate in Experiment 1b. Participants were assigned to the same groups of blinkers and non-blinkers as in Experiment 1a. Note that the individuals who consistently show no AB in an alphanumeric AB task as demonstrated in Experiment 1a (i.e., non-blinkers) might show an AB under the experimental conditions of Experiment 1b. To consistently refer to these individuals in Experiments 1a and 1b, we will continue to label them as 'non-blinkers', keeping in line with the literature on non-blinkers (Martens et al., 2009; Martens, Korucuoglu, et al., 2010).

Stimuli and apparatus. The same stimuli and apparatus were used as in Experiment 1a, except that all stimuli consisted of consonant letters. Again 'V', 'Q', 'Y' were excluded. Targets were presented in red, whereas distractors were presented in black.

Procedure. The procedure was the same as in Experiment 1a, except that all stimuli were presented for 120 ms, such that a similar level of difficulty was obtained as in Experiment 1a. Furthermore, the RSVP consisted of 16 stimuli, and T1 was always presented as the fifth item in the stream. Experiment 1b took approximately 35 minutes to complete.

EXPERIMENT 2

The aim of Experiment 2 was to strengthen the results found in Experiment 1b by replicating the results in a larger sample of participants, enabling us to study a wider range of individual differences.

Participants. A total of 132 volunteers (98 women) recruited from the University of Groningen participated in the experiment in return for course credits. Unfortunately, due to technical problems, the age related information of the participants was lost for this experiment. However, because participants were selected from a similar pool of participants as in Experiment 1, it can be assumed that the average age of the participants in both experiments was equivalent. They had normal or corrected-to-normal visual acuity, normal hearing, and no history of neurological problems. The Neuroimaging Center Institutional Review Board approved the experimental protocol and each participant signed a written consent prior to the experiment.

Stimuli and apparatus. The stimuli and apparatus were the same as in Experiment 1b.

Procedure. The procedure was similar to that in Experiment 1b. The experiment consisted of one practice block of 14 trials and three testing blocks of 96 trials each. Participants were allowed to take a short break between blocks. They completed the experiment in approximately 45 minutes.

RESULTS AND DISCUSSION

When appropriate, Greenhouse-Geisser-corrected p values are reported ($\varepsilon < 0.75$). In addition, a Bonferroni-correction was applied when independent t-tests were performed serving as post-hoc test.

EXPERIMENT 1A

To assure that participants were assigned to the appropriate group, AB magnitude was first computed for each individual by calculating the percentage decline in T2 accuracy at lags 2 and 3 relative to T1 accuracy across lags. Following previ-

ous non-blinker studies (Chua, 2005; Martens & Johnson, 2009; McLaughlin et al., 2001), the AB magnitude was calculated as a function of T1 accuracy by using the following formula:

$$\text{AB magnitude} = \left(\frac{\overline{T1} - T2 \mid T1_{lag2}}{\overline{T1}} + \frac{\overline{T1} - T2 \mid T1_{lag3}}{\overline{T1}} \right) / 2 * 100,$$

where $\overline{T1}$ is the mean accuracy of T1, and $T2 \mid T1_{lag}$ is the mean accuracy of T2 at a specific lag given that T1 was correctly reported. We used this particular method to assure that individuals with a high T1 accuracy, but overall low T2 accuracy were not erroneously classified as non-blinkers. However, alternative ways to calculate AB magnitude, for instance by relating T2 accuracy at lags 2 and 3 to T2 accuracy at lag 8 produced comparable results. Mean AB magnitude was 8.7% for the non-blinkers, ranging from 2.5% to 15.3%, suggesting that each individual within this group indeed showed little or no AB. For the blinkers, mean AB magnitude was 32.6%, ranging from 17.0% to 50.6%, suggesting that they showed a moderate to large AB.

Figure 3.1 shows target accuracy as a function of the interval between the two targets (lag), for non-blinkers (circle symbols) and blinkers (square symbols). A repeated measures analysis of variance (RM-ANOVA) of T1 accuracy with group (non-blinkers and blinkers) as a between-subjects factor and lag (1, 2, 3, and 8) as a within-subjects factor revealed a significant effect of group, $F(1, 26) = 13.49$, $MSE = 166.64$, $p = .001$, $\eta^2p = .34$, reflecting mean accuracy to be higher for non-blinkers (90.4%) than for blinkers (81.4%). In addition, a main effect of lag was found, $F(2.17, 56.49) = 33.27$, $MSE = 29.43$, $p < .001$, $\eta 2p = .56$, such that performance at lag 1 was relatively low. The Group × Lag interaction was not significant ($p = .23$).

An RM-ANOVA of T2 performance given correct report of T1 (T2 | T1) with group as a between-subjects factor and lag as a within-subjects factor revealed a significant effect of group, $F(1, 26) = 28.75$, $MSE = 406.53$, $p < .001$, $\eta^2p = .53$; lag, $F(3, 78) = 33.63$, $MSE = 84.49$, $p < .001$, $\eta^2p = .56$; and a significant Group × Lag interaction, $F(3, 78) = 7.94$, $MSE = 84.49$, $p = .001$, $\eta^2p = .23$. Separate analyses in which lag 1 was excluded revealed that non-blinkers did not show a significant AB ($p = .38$), whereas blinkers did, $F(2, 28) = 8.11$, $MSE = 119.22$, $p = .002$, $\eta^2p = .37$.

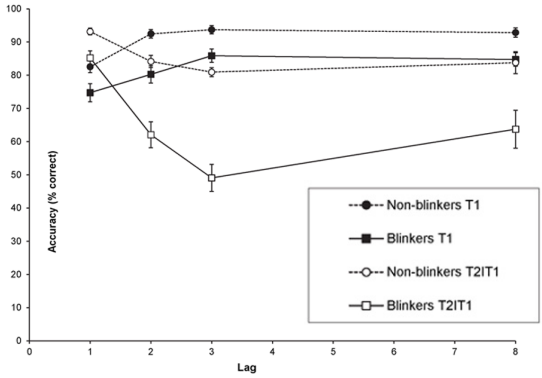


Figure 3.1 Target accuracy in Experiment 1a. Mean percentage correct report of T1 (black symbols) and T2 given correct report of T1 (white symbols) as a function of lag, for non-blinkers (circles) and blinkers (squares). Error bars reflect standard error of the mean.

Order reversals. We calculated the relative percentage of order reversals over the trials where T1 and T2 were both correctly reported, providing a measure of order reversals that is irrespective of individual differences in identification accuracy. Interestingly, there was a significant effect of group, $F(1, 26) = 5.96$, $MSE = 152.26$, $p = .022$, $\eta^2p = .19$, such that non-blinkers showed

relatively fewer order reversals than blinkers did (11.1% vs. 16.8%, respectively). In addition, we found an effect of lag, $F(3, 78) = 83.99$, $MSE = 51.77$, $p < .001$, $\eta^2p = .76$, as the number of order reversals decreased as a function of lag (30.8%, 14.8%, 10.0%, and .9% at lags 1, 2, 3, and 8, respectively). Also a marginally significant Group × Lag interaction was found, $F(3, 78) = 2.71$, $MSE = 51.77$, $p = .051$, $\eta^2p = .09$, such that particularly at lags 2 and 3, non-blinkers seemed to show fewer order reversals than blinkers did.

EXPERIMENT 1B

Figure 3.2 shows target accuracy as a function of lag, for non-blinkers and blinkers. Mean T1 accuracy was 90.0% for the blinkers and 91.9% for the non-blinkers. An RM-ANOVA of T1 performance revealed no significant effects ($ps > .10$).

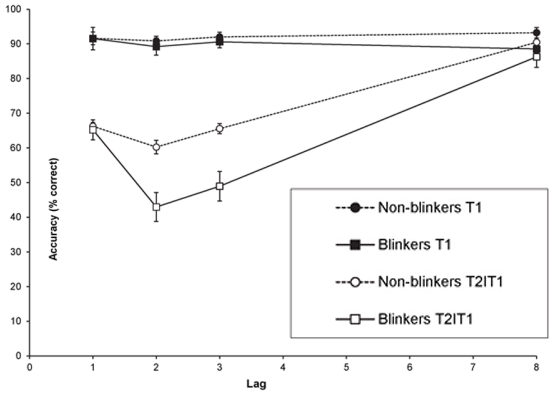


Figure 3.2. Target accuracy in Experiment 1b. Mean percentage correct report of T1 and T2 given correct report of T1 as a function of lag, for non-blinkers and blinkers. Error bars reflect standard error of the mean.

An RM-ANOVA of T2|T1 revealed a significant effect of group, $F(1, 26) = 8.98$, $MSE = 296.76$, $p = .006$, $\eta^2p = .26$; lag, $F(3, 78) = 73.40$, $MSE = 99.27$, $p < .001$, $\eta^2p = .74$; and a significant Group × Lag interaction, $F(3, 78) = 4.93$, $MSE = 99.27$, $p = .007$, $\eta^2p = .16$. Mean AB magnitude was 31.6% for non-blinkers and 49.0% for blinkers ($t(26) = 3.53$, $SE = 4.95$, $p = .002$). These findings suggest that both the blinkers as well as the non-blinkers showed a sizeable AB, but that it was substantially smaller in the non-blinkers than in the blinkers.

A positive Pearson product-moment correlation was found between individual AB magnitudes in Experiments 1a and 1b, $r = .42$, $p = .027$. A similar correlation was found for T2|T1 performance, $r = .44$, $p = .019$, but not for T1 performance ($p = .14$). These findings suggest that although AB magnitude was generally larger in Experiment 1b than in Experiment 1a, individuals with a relatively small or large AB in Experiment 1a continued to show a relatively small or large AB in Experiment 1b, respectively.

Suppression. We estimated the efficacy of selection (A) as the proportion of trials during which an item was reported from a 7-item window around the target (spanning three items before to three items after the target) as follows:

$$A = \sum_{i=ks}^{ke} P_i ,$$

where Pi is the probability (i.e., empirical frequency) of reporting an item from serial position i relative to the target position ($i = 0$), and ks and ke are the lower and upper bounds, respectively, of the window used to compute the measure (in this case, -3 and 3, respectively). Thus, we calculated how frequent each participant reported a letter from the 7-item window surrounding T1 or T2 to indicate the availability of the distractors

around the target. In contrast to the previous analyses, order reversals were counted as incorrect, because for these and the following analyses we were interested in the exact serial location of the reported letters. As shown in Figure 3.3, performance within the 7-item window was close to or at ceiling for both blinkers and non-blinkers. Given that 17 different letters could be presented within the stream, the chance to randomly select a letter within the 7-item window was 7/17 (i.e., 42%). A paired t-test revealed that the accuracy of reporting an item within the 7-item window differed significantly from the level of chance, $t(27) = 60.0$, $SE = .9$, $p < .001$; $t(27) = 74.29$, $SE = .74$, $p < .001$; $t(27) = 61.0$, $SE = .91$, $p < .001$; $t(27) = 68.5$, $SE = .82$, $p < .001$ for lags 1, 2, 3, and 8, respectively. An RM-ANOVA of T1 showed an effect of lag, $F(3, 78) = 4.1$, $MSE = 1.09$, $p = .009$, $\eta^2p = .14$, but both the Group x Lag interaction ($p = .66$), as the effect of group ($p = .62$) were non-significant.

An RM-ANOVA of T2|T1 revealed a significant effect of group, $F(1, 26) = 9.87$, $MSE = 21.05$, $p = .004$, $\eta^2p = .28$, whereas neither the effect of lag ($p = .27$) nor the Group × Lag interaction ($p = .91$) was significant. These findings suggest that overall, little or no suppression seemed to be present, and that the AB did not induce any suppression as a function of lag in this study. Given that many theoretical and computational models of the AB assume that the AB is caused by the suppression that is induced by T1 and/or the distractor that immediately follows T1 (Dux & Marois, 2008; Olivers, 2007; Vogel et al., 1998; Vul, Nieuwenstein, et al., 2008), it is striking to find no evidence for an AB-induced suppression effect for T2, which would otherwise be reflected in a sizeable drop in performance during lags 2 and 3. However, it is important to note that because performance in the current experiment was close to ceiling, such an effect might be concealed. Figure 3.4 provides a more detailed picture regarding the distribution of T2|T1 reports, revealing that participants tend to report either the letter preceding or following the second target when making intrusion errors. We will discuss this pattern of intrusions

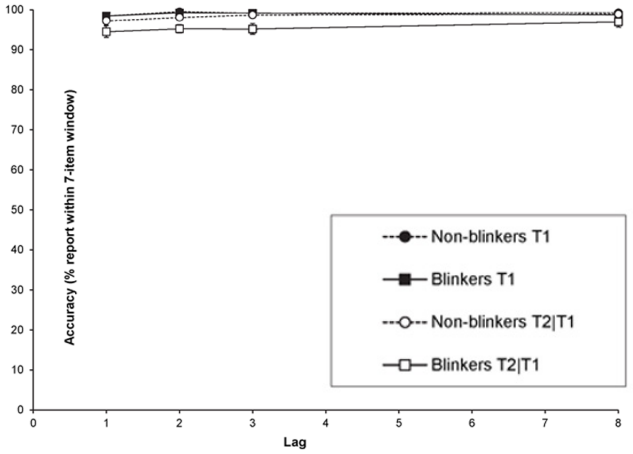


Figure 3.3. Suppression in Experiment 1b. Suppression of the temporal selection process expressed as the accuracy of reporting an item within the 7-item window around a given target as a function of lag, for blinkers and non-blinkers.

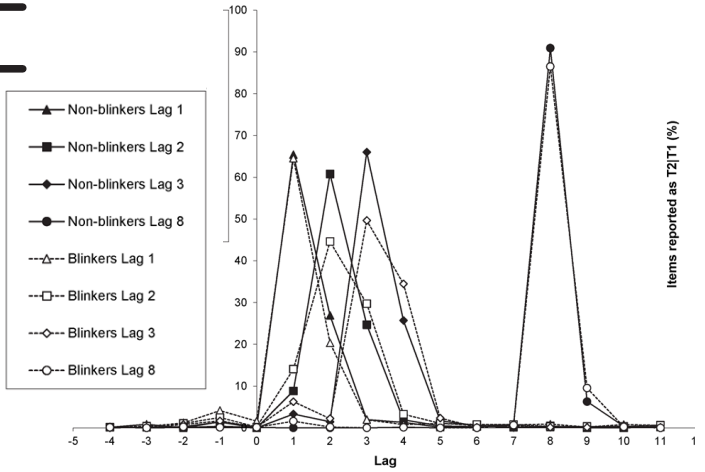


Figure 3.4. Distribution of T2|T1 reports in Experiment 1b. The percentage of letters at a particular position in the RSVP stream that were reported as T2 given correct report of T1 as a function of lag, for blinkers and non-blinkers.

further in the section below on 'relative T2+3 intrusions'.

Delay. In order to measure the latency of these intrusion errors in a similar manner as (Chun, 1997; Vul, Nieuwenstein, et al., 2008) did, we calculated the center of mass (C) of reports in the window around a given target as follows:

$$C = \frac{\sum_{i=Ks}^{ke} P_i * i}{A}$$

Originally employed by Chun (1997), the center of mass corresponds to the average reported serial position relative to the target. A positive center of mass indicates that participants are more likely to report items following the target, whereas a negative center of mass would indicate a bias to report items preceding the target. If the center of mass is more positive for T2 than for T1, this means that selection is delayed for T2 relative to T1. Order reversals were counted as incorrect in this analysis.

Figure 3.5 shows the measure of delay for T1 and T2 as a function of lag, for blinkers and non-blinkers. An RM-ANOVA of the center of mass for T1 only revealed a significant main effect of lag, $F(3, 78) = 3.03$, $MSE = .004$, $p = .045$, $\eta^2p = .1$. For T2|T1 we found an effect of lag, $F(2.1, 54.64) = 6.48$, $MSE = .02$, $p = .003$, $\eta^2p = .20$; no main effect of group ($p = .35$); and a Group × Lag interaction, $F(2.1, 54.64) = 3.63$, $MSE = .02$, $p = .03$, $\eta^2p = .12$. The non-blinkers show a delay that is particularly pronounced at lag 1, whereas for blinkers the strongest delay is observed at lag 3. Independent samples t-tests revealed a significant difference between non-blinkers and blinkers at lag 1 only, $t(26) = 3.88$, $SE = .51$, $p = .001$. This might reflect a difference in the use of letters following the second target for the two groups, however, it must be noted that this could also reflect a difference in the binding of letter identity and color, which is discussed more extensively in the general discussion.

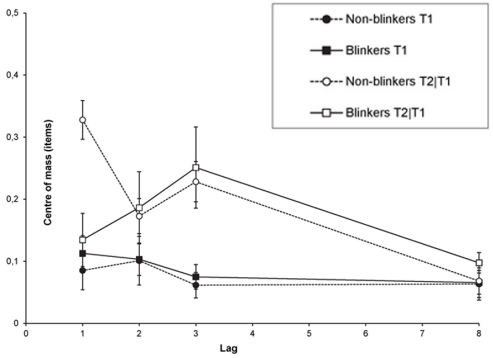


Figure 3.5. Delay in Experiment 1b. Delay of the temporal selection process expressed as the center of mass of reports in the selection window around a given target as a function of lag, for blinkers and non-blinkers.

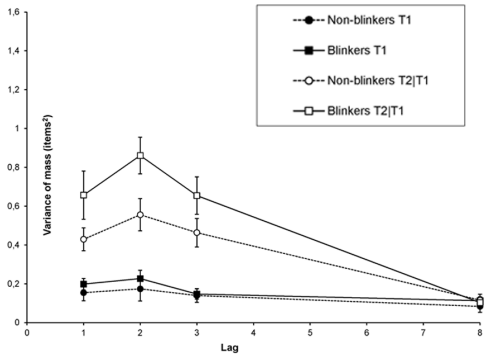


Figure 3.6. Diffusion in Experiment 1b. Diffusion of the temporal selection process expressed as the variance of the center of mass in the selection window around T1 or T2 as a function of lag, for blinkers and non-blinkers.

Diffusion. Similarly to Vul, Nieuwenstein, et al. (2008), we estimated the precision of selection around the center of mass (see Figure 3.6) by calculating the variance of the center of mass (V), as follows:

$$V = \frac{\sum_{i=ks}^{ke} P_i * (i - C)^2}{A}$$

Here, the variance of the center of mass reveals to which extent the reports of the letters are diffused around the center of mass, reflecting the spread of selection. Again, order reversals were counted as incorrect.

For T1, we only found a significant effect of lag, $F(1.82, 47.36) = 6.41$, $MSE = .01$, $p = .004$, $\eta^2p = .2$; whereas for T2|T1 we found a significant effect of group, $F(1, 26) = 4.29$, $MSE = .21$, $p = .048$, $\eta^2p = .14$; and lag, $F(2.2, 57.2) = 33.01$, $MSE = .08$, $p < .001$, $\eta^2p = .56$; but no significant Group × Lag interaction ($p = .11$). These results clearly reflect that - compared to non-blinkers - blinkers are less precise in selecting the second but not the first target.

Relative T2+3 intrusions. The relatively high performance within the 7-item window reveals that response errors were far from random, as illustrated in Figures 3.3 and 3.4. The latter figure indicates that for lags 2 and 3, blinkers show more post-target intrusions than non-blinkers do. However, blinkers show more errors overall, so a more meaningful comparison would be to determine the pattern of relative intrusion errors, controlling for differences in the total error rate. To that end, we examined the percentage of erroneously selected letters presented at one to three serial positions following a target, relative to all errors on a given lag. Order reversals were counted as incorrect. For T1, as well as for T2 at lag 8, the number of post-target intrusions was insufficient to allow for a meaningful analysis. Therefore, this analysis was restricted to T2|T1 at lags 1 to 3 only. For this analysis, the average number of trials over participants available in blinkers was 16.3, 25.3, and 27.0 for lags 1, 2, and 3, respectively. In non-blinkers this was 21.2, 19.8, and 20.4 for lags 1, 2, and 3, respectively.

In Figure 3.7 the percentage T2+3 intrusions relative to all errors on a given trial are plotted as a function of lag. An RM-ANOVA of the T2+3 intrusions with lag (1, 2, and 3) as a within-subjects factor and group (non-blinkers and blinkers) as a between-subjects factor revealed significant effects for lag, $F(1.46, 37.91) = 7.97$, $MSE = 264.53$, $p = .003$, $\eta^2p = .24$; and group, $F(1, 26) = 9.93$, $MSE = 339.4$, $p = .004$, $\eta^2p = .28$; but a significant Group × Lag interaction was not found ($p = .48$). Thus, compared to blinkers, when a selection error was made, the T2 response of non-blinkers more frequently matched one of the items following the second target. In contrast to the pattern of absolute intrusion rates (see Figure 3.4), the current analysis of relative post-target intrusions shows that this was not only the case at lag 1, but also at lags 2 and 3.

Order reversals. The percentage of order reversals for trials during which T1 and T2 were both correct was 8.3%, .3%, .5%, and .2% at lags 1, 2, 3, and 8, respectively. A significant main effect of lag reflected the decrease of order reversals as a function of lag, $F(1.1, 28.39) = 23.83$, $MSE = 49.52$, $p < .001$, $\eta^2p = .48$. No effect of group ($p = .6$) or an interaction effect between group and lag ($p = .54$) was found, suggesting no difference in order reversals between non-blinkers and blinkers. Given that AB magnitude was larger in Experiment 1b than in Experiment 1a for both groups, it is perhaps surprising that there were substantially more order reversals in Experiment 1a. An explanation might at least partially lie in the fact that the SOA was much shorter in Experiment 1a (80 ms) than in Experiment 1b (120 ms).

EXPERIMENT 2

After initial analysis, 21 students were excluded from further analyses due to insufficient identification performance of T1 (<70%). In total, 111 participants remained for further analyses. Given that Experiment 2 featured a wide range of AB magnitudes, we treated AB magnitude in the analyses of Experiment 2 as a continuous variable. However, for the sake of clarity, figures for Experiment 2 feature three subgroups, based on individuals' AB magnitude in the first block of the experiment. Mean AB magnitude was 15.9% (range = 1.3-27.0%) for the group of 'small blinkers', 39.1% (range = 27.0-47.5%) for the group of 'medium blinkers', and 60.3% (range = 48.2-92.8%) for the group of 'large blinkers'.

In Figure 3.8, T1 accuracy and T2|T1 accuracy are plotted as a function of lag (1, 2, 3, and 8), for the small blinkers (circle symbols), the medium blinkers (triangle symbols), and the large blinkers (square symbols). An RM-ANCOVA of T1 performance with lag (1, 2, 3, and 8) as a within-subjects factor and AB magnitude as a continuous between-subjects factor (i.e., covariate) revealed no effect of lag ($p = .07$), but there was a main effect of AB magnitude, $F(1, 109) = 22.37$, $MSE = 116.0$, $p < .001$, $\eta^2p = .17$, and a significant AB magnitude × Lag interaction, $F(3, 327) = 3.3$, $MSE = 10.63$, $p = .022$, $\eta^2p = .03$.

An RM-ANCOVA of T2|T1 revealed an effect of lag, $F(3, 327) = 40.93$, $MSE = 63.83$, $p < .001$, $\eta^2p = .27$; AB magnitude, $F(1, 109) = 365.59$, $MSE = 134.9$, $p < .001$, $\eta^2p = .77$; and a significant AB magnitude × Lag interaction, $F(3, 327) = 90.39$, $MSE = 63.83$, $p < .001$, $\eta^2p = .45$. These results confirm the presence of clear individual differences in AB magnitude, as illustrated in Figure 3.8.

Suppression. The amount of suppression was calculated in the same manner as in Experiment 1b. Again, a paired t-test revealed that the accuracy within the 7-item window differed significantly from the level of chance, *t(110) = 61.47, SE = .82, p < .001; t(110) = 99.74, SE = .52, p < .001; t(110) = 95.43, SE = .56, p < .001; t(110) = 199.97, SE = .56,* p < .001 for lags 1, 2, 3, and 8, respectively.

Figure 3.9 shows the accuracy within a 7-item window for T1 and T2|T1 as a function of lag, for the different groups. An RM-ANCOVA of T1 showed an effect of AB magnitude, F(1, 109) = 23.42, MSE = 6.45, p < .001, η^2p = .18; but no significant effect of lag (p = .45) or an AB magnitude × Lag interaction (p = .45).

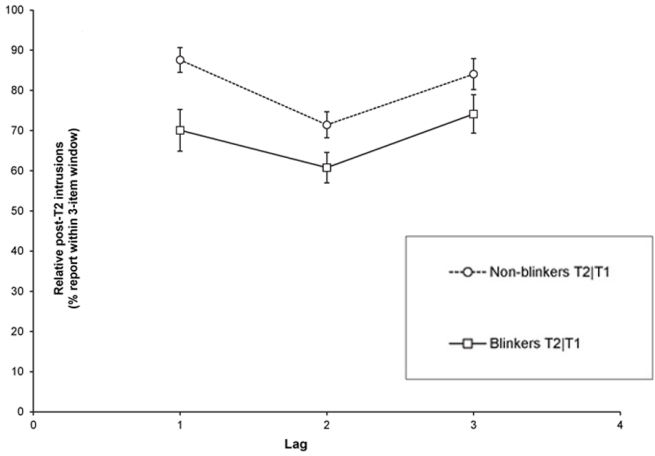


Figure 3.7. Intrusion errors in Experiment 1b. Percentage of erroneously selected letters (relative to all trials with an incorrect T2 response) presented 1-3 serial positions following T2 as a function of lag, for blinkers and non-blinkers.

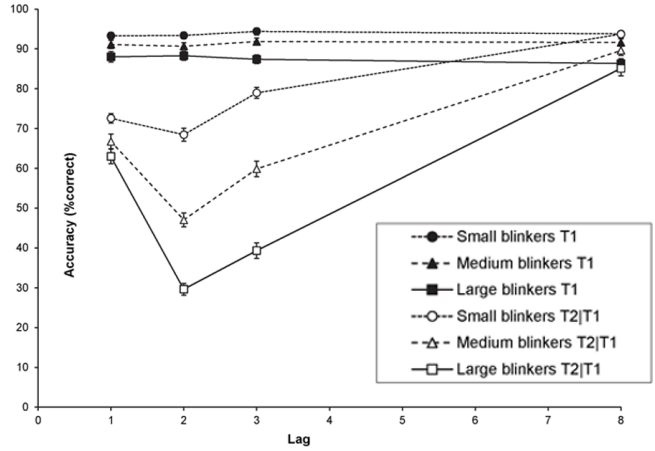


Figure 3.8. Target accuracy in Experiment 2. Mean percentage correct report of T1 (black symbols) and T2 given correct report of T1 (white symbols) as a function of lag, for small blinkers (circles), medium blinkers (triangles), and large blinkers (squares). Error bars reflect standard error of the mean.

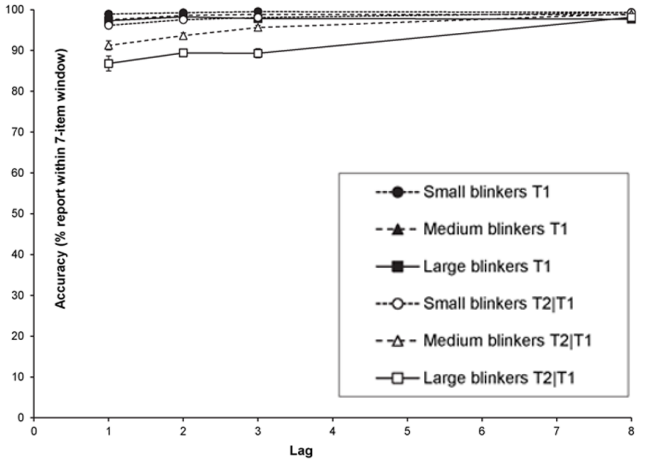


Figure 3.9. Suppression in Experiment 2. Suppression of the temporal selection process expressed as the accuracy of reporting an item within the 7-item window around a given target as a function of lag, for small, medium, and large blinkers.

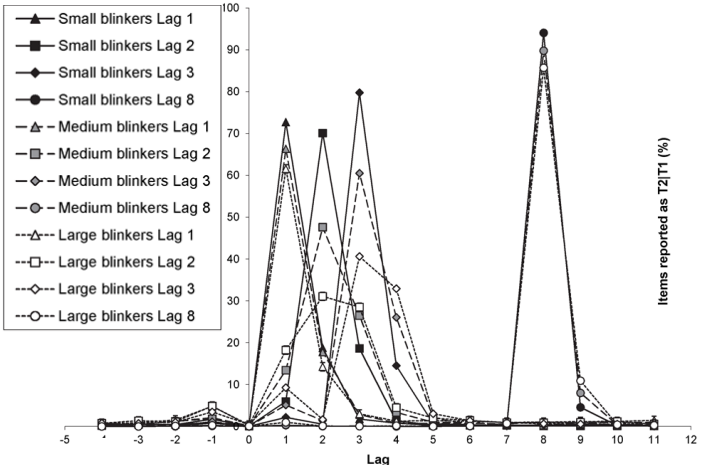


Figure 3.10. Distribution of T2|T1 reports in Experiment 2. The percentage of letters at a particular position in the RSVP stream that were reported as T2 given correct report of T1 as a function of lag, for small, medium, and large blinkers.

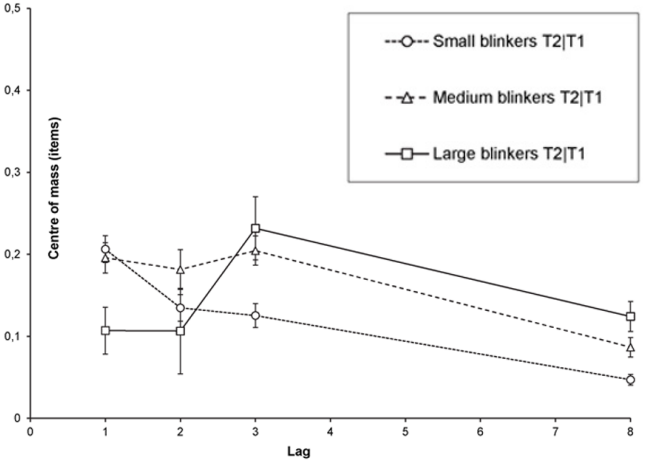


Figure 3.11. Delay in Experiment 2. Delay of the temporal selection process expressed as the center of mass of reports in the selection window around a given target as a function of lag, for small, medium, and large blinkers.

An RM-ANCOVA of T2|T1 revealed no effect of lag (p = .30), but there was an effect of AB magnitude, $F(1, 109) = 88.29$, $MSE = 46.76$, $p < .001$, $\eta^2p = .45$; and an AB magnitude × Lag interaction, $F(1.94, 211.65) = 14.81$, $MSE = 29.47$, $p < .001$, $\eta^2p = .12$. Thus, as can be seen in Figure 3.9, little or no suppression occurred in small blinkers, whereas suppression of distractors as a function of lag clearly occurred in large blinkers. However it must be noted that, as in Experiment 1b, the ceiling effect might be a restrictive factor here.

The distribution of T2|T1 reports can be found in Figure 3.10. Here it can be seen that, again, the main contributors of the high accuracy in the 7-item window are the reports of the targets either preceding or following the target, plus the reports of the target itself.

Delay. The amount of delay during the temporal selection process was calculated as in Experiment 1b. The results for T2|T1 as a function of lag are plotted in Figure 3.11. For the sake of clarity, T1 is not plotted. An RM-ANCOVA of T1 showed an effect of lag, $F(3, 327) = 4.18$, $MSE = .003$, $p = .006$, $\eta^2p = .04$; and AB magnitude, $F(1, 109) = 7.99$, $MSE = .02$, $p = .006$, $\eta^2p = .07$; but no significant AB magnitude × Lag interaction was found (p = .66).

For T2|T1, an RM-ANCOVA showed an effect of lag, $F(3, 327) = 12.81$, $MSE = .02$, $p < .001$, $\eta^2p = .11$; no main effect of AB magnitude (p = .33); but a significant AB magnitude × Lag interaction, $F(3, 327) = 12.54$, $MSE = .02$, $p < .001$, $\eta^2p = .10$. As shown in Figure 3.11, consistent with our findings in Experiment 1b, there was a remarkable delay at lag 1 for small blinkers, whereas for large blinkers the delay was most pronounced at lag 3.

Diffusion. Shown in Figure 3.12, diffusion during the temporal selection process was calculated as in Experiment 1b. An RM-ANCOVA of T1 revealed a main effect of AB magnitude, $F(1, 109) = 7.55$, $MSE = .09$, $p = .007$, $\eta^2p = .07$; but no significant effect was found of lag (p = .24) or AB magnitude × Lag interaction (p = .76).

For T2|T1 we found a significant effect of lag, $F(3, 327) = 9.64$, $MSE = .05$, $p < .001$, $\eta^2p = .08$; AB magnitude, $F(1, 109) = 164.85$, $MSE = .16$, $p < .001$, $\eta^2p = .60$; and also an AB magnitude × Lag interaction, $F(3, 327) = 60.16$, $MSE = .05$, $p < .001$, $\eta^2p = .36$. These results clearly confirm the results of Experiment 1b, namely that the temporal selection process of small blinkers is more precise than that of large blinkers. The significant interaction with lag as observed in the current experiment indicates that this is especially the case during the AB interval.

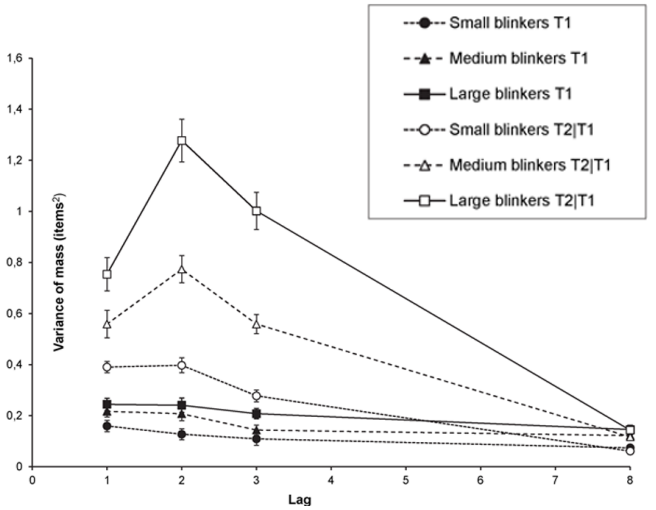


Figure 3.12. Diffusion in Experiment 2. Diffusion of the temporal selection process expressed as the variance of the center of mass in the selection window around T1 or T2 as a function of lag, for small, medium, and large blinkers.

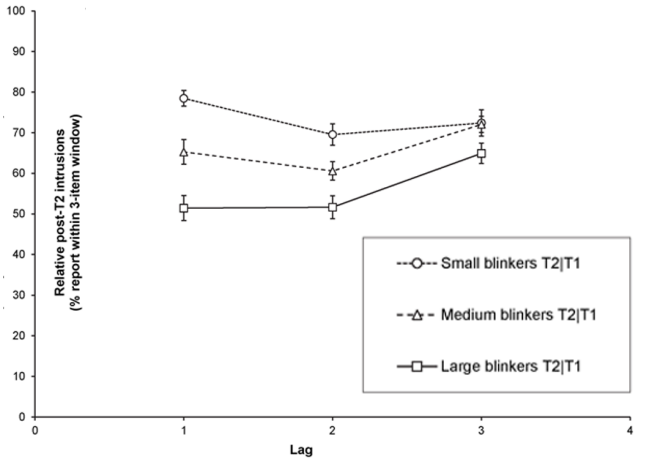


Figure 3.13. Intrusion errors in Experiment 2. Percentage of erroneously selected letters (relative to all trials with an incorrect T2 response) presented 1-3 serial positions following T2 as a function of lag, for small, medium, and large blinkers.

Relative T2+3 intrusions. Focusing on lags 1 to 3, we examined the percentage of erroneously selected letters presented one to three serial positions following T2 relative to all errors on a given lag, as shown in Figure 3.13. For this analysis, the average number of trials over participants available was 14.4, 21.1, and 19.9 for lags 1, 2, and 3, respectively.

An RM-ANCOVA revealed a significant effect of lag, $F(2, 218) = 4.6$, $MSE = 177.7$, $p = .011$, $\eta^2p = .04$; AB magnitude, $F(1, 109) = 61.52$, $MSE = 368.31$, $p < .001$, $\eta^2p = .36$; and AB magnitude × Lag, $F(2, 218) = 10.09$, $MSE = 177.7$, $p < .001$, $\eta^2p = .09$, such that small blinkers made relatively more post-target intrusions than large blinkers did, particularly at the shorter lags (see Figure 3.13). Thus, besides making fewer mistakes, small blinkers made more educated guesses with the T2 response frequently matching with one of the subsequent items in the RSVP stream.

Order reversals. As in the former experiments, we calculated the percentage of order reversals for trials during which T1 and T2 were both reported correctly. Here, we found no effect of lag ($p = .065$), but there was a significant effect of AB magnitude, $F(1, 109) = 24.38$, $MSE = 15.18$, $p < .001$, $\eta^2p = .18$; and a significant AB magnitude × Lag interaction, $F(1.14, 124.34)=19.09$, $MSE = 10.8$, $p < .001$, $\eta^2p = .15$, such that large blinkers had more order reversals than small blinkers did, particularly at the short lags. These results suggest that a small or absent AB does not come at a cost for temporal order information, and is better preserved for small blinkers than for large blinkers.

GENERAL DISCUSSION

The aim of this study was threefold. Previously, we found that some individuals show little or no AB when required to identify two target letters presented in a sequential stream of non-target digits. Our first goal was to investigate whether these 'non-blinkers' would continue to show no AB when required to identify two red target letters amongst a stream of black non-target letters, thus testing the generality of their remarkable ability in avoiding an AB. Earlier, it was found that they failed to do so when targets had to be selected based on rotation or semantic features (Martens, Dun, et al., 2010; Martens, Korucuoglu, et al., 2010). After replicating the differential performance between blinkers and non-blinkers in a standard alphanumeric AB task, we found that when targets and distractors could only be distinguished on the basis of color, a substantial AB occurred in both groups. Though color is a stimulus property that is available relatively early in the processing pathway (Rotte et al., 1997; Smid & Heinze, 1997; Wijers, 1989), apparently early target selection was not possible to the extent that non-blinkers failed to avoid the occurrence of an AB. Combined with the previous observation of an AB in non-blinkers when alphanumeric stimuli were presented in the auditory modality (Martens et al., 2009), the current results seem to suggest that the non-blinkers' ability might indeed be quite task-specific, requiring the presence of visual alphanumeric category information. However, given that AB magnitude in our colored targets task remained smaller in non-blinkers than in blinkers, there must be more to the story.

Interestingly, the colored targets paradigm as employed here allowed us to study individual differences in target selection efficiency in more detail. More specifically, our second aim was to study possible differences in the temporal profile of blinkers and non-blinkers by examining the amount of suppression, delay, and diffusion of the temporal selection process during the AB (Vul, Nieuwenstein, et al., 2008). We expected to find differences in these three dissociable dimensions of temporal selection, because even in the colored target task clear differences in AB magnitude were observed.

SUPPRESSION

Surprisingly, little suppression was observed in both Experiments 1b and 2; The efficacy of selection, measured as the percentage of trials during which an item was reported from a 7-item window around either T1 or T2 (i.e., spanning three items before to three items after the target), was generally high. In Experiment 1b, a significant difference between blinkers and non-blinkers in the amount of suppression for T2 was found, which, however, was not modulated by lag. This finding is similar to what was reported by Popple & Levi (2007). It must be noted though that in their study, as well as in the current one, patterns of AB-induced suppression may have been obscured by ceiling effects.

In Experiment 2, employing a larger sample of subjects and thus, a wider range of AB magnitudes, the interaction of AB magnitude and lag reflected signs of suppression of T2 and the surrounding distractors at the shortest lags for large blinkers, whereas small blinkers continued to show no suppression whatsoever. Although the finding of suppression as a function of lag corresponds with findings from previous studies (Botella et al., 2011; Chun, 1997; Vul, Nieuwenstein, et al., 2008), all of these papers reported substantially more suppression.

An explanation for these differential findings might lie in differences in methods, stimuli, and overall task difficulty. Whereas both our study and that of Popple & Levi (2007) employed integral dimensions of the stimuli as the relevant features (color and shape), Vul, Nieuwenstein, et al. (2008) as well as Chun (1997) used composed targets (a letter surrounded by an annulus or colored frame). Although the study by Botella et al. (2011) did use color as an integrated target feature, they introduced a task-switch by varying the color of the two targets, and possibly reduced the effectiveness of color as a target-specific feature by also varying the color of each distractor in the stream. It is thus not inconceivable that the latter studies introduced additional factors into the AB task that further complicated the binding and subsequent selection of targets. In addition, the level of overall performance in (Vul, Nieuwenstein, et al., 2008) was dramatically low (~10-50%), making comparisons with other AB studies - that typically feature much higher performance - difficult.

Another notable finding pertains to the individual differences in the amount of suppression. In multiple studies it has been suggested that the AB is due to a failure to effectively suppress distractors (Dux et al., 2006; Dux & Harris, 2007; Dux & Marois, 2008; Harris et al., 2010b). Specifically, based on findings in their priming study, Dux & Marois (2008) suggested that large blinkers in particular fail to suppress the processing of irrelevant distractors, whereas small blinkers

frequently manage to avoid an AB by successful suppression of these distractors. If that would indeed be the case, however, one would expect to see strong suppression in non-blinkers and little or no suppression in large blinkers, exactly opposite to the pattern of findings reported here.

Instead, we propose that non-blinkers are somehow able to select targets at an earlier processing stage than blinkers do, to some extent even when targets are not defined by alphanumeric category. Consequently, compared to blinkers, non-blinkers may have little need to suppress distractors, as stable target representations can more readily and easily be formed. The less effective this early selection, the stronger the need for suppression at a later stage of processing, a pattern that is indeed in line with the levels of suppression that we observed in small, medium, and large blinkers, respectively (see Figure 3.9). However, it must be noted that given the relatively modest amount of suppression observed in the current study, it is hard to conceive that suppression alone can account for the significant AB that was obtained in the majority of participants. Moreover, it remains puzzling why the strongest suppression tended to occur at lag 1, whereas the strongest AB was consistently found at lag 2.

DELAY

Another surprising finding emerged in the latency measure of the intrusion errors. Following Chun (1997), and Vul, Nieuwenstein, et al. (2008), the center of mass was calculated as a measure of delay. Whereas for large blinkers, the maximal delay was consistently found at lag 3, for small blinkers the maximum in both experiment 1b and 2 was observed at lag 1. This latter finding, however, may at least partly reflect an artefact of the T2 center of mass calculation, and at first sight does not seem to be very meaningful. That is, the small blinkers' seemingly large delay at lag 1 may be the simple consequence of a) the fact that the diffusion of responses was substantially smaller for small blinkers than for large blinkers (who made intrusions from a wider window; see section below), b) the fact that small blinkers made relatively more post-target intrusions than blinkers did (see Figures 3.7 and 3.13), and c) the fact that correct T1 responses are excluded from the calculation. The combination of these factors at lag 1 may thus be responsible for an inflated center of mass for small blinkers, and a center of mass that is close to zero for large blinkers. However, given that the results found here correspond to the pattern of relative post-target intrusion errors (further discussed below), they may nevertheless reflect a genuine difference between small and large blinkers.

The pattern of results is quite different from that reported by Chun (1997) and Vul, Nieuwenstein, et al. (2008), who both reported finding a negative center of mass at the shortest lags. Again, an explanation might lie in differences in methods, stimuli, and overall task difficulty, as well as the fact that their participants showed more suppression than the individuals in the current study did.

DIFFUSION

Perhaps the most telling and straightforward finding is provided by the measure of diffusion, expressing the precision of selection for each group of individuals. Calculated as the variance of the center of mass, the amount of diffusion

showed a consistent pattern that matched closely with that of the AB, reaching the lowest temporal precision at lag 2. Although the amount of overall diffusion was much lower than that reported by Vul, Nieuwenstein, et al. (2008), the pattern of diffusion as a function of time between the targets is very similar. In addition, our current findings clearly showed that, compared to small blinkers, large blinkers were less precise in selecting the second but not the first target.

This pattern of diffusion fits with the idea that non-blinkers are able to select targets at an earlier processing stage than blinkers do. Early target selection may reduce interference from distractors, allowing subsequent processing of the targets to proceed faster and more accurately in non-blinkers than in blinkers, reflected in earlier P3s (Martens, Korucuoglu, et al., 2010; Martens, Munneke, et al., 2006) and less diffusion.

RELATIVE INTRUSION ERRORS

In addition to these three dimensions of temporal selection, we analyzed the percentage of erroneously selected letters presented one to three serial positions following T2 relative to all errors on a given lag (see Figures 3.7 and 3.13). Errors in the temporal selection process have been studied before (Botella et al., 2011; Chun, 1997; Popple & Levi, 2007), but individual differences were not considered and differences in the total number of errors were not controlled for. Given that intrusions of items following T2 are inherently related to the total number of errors made, we studied the relative number of intrusions, allowing comparisons between blinkers and non-blinkers in the type of intrusions irrespective of the total rate of response errors. In both Experiments 1b and 2, we found that non-blinkers and small blinkers made relatively more post-T2 intrusions than blinkers did. In Experiment 2, within the group of small blinkers, most post-T2 intrusions were made at lag 1, whereas within the group of large blinkers most of these intrusions occurred at lag 3. This pattern matches quite well with the differences in delay that we observed for the different groups, but poses a challenge in terms of interpretation. Although we argued that the latter differences might at least partly be due to the way in which the center of mass was calculated, the significant interaction between group and lag in the relative post-T2 intrusions does indicate systematic differences in the selection process employed by blinkers and non-blinkers, especially at lag 1.

Note however, that some caution is generally required in the interpretation of what a shift in the center of mass as well as the number of relative post-target intrusion errors actually reflect. Given that the particular task employed in the current study required the binding of a color to a particular letter, the delay that is associated with a positive shift in the center of mass or an increase in post-target intrusions may be due to non-blinkers and blinkers having differential processing speeds in either the color, letter, or the binding of features (or a combination thereof). Future research is needed to isolate these different components of the temporal selection process.

RELATIVE ORDER REVERSALS

In response to the proposition that the AB reflects a cognitive strategy of enforcing an episodic distinction between successive stimuli of Wyble

et al. (2009), our third and final aim was to determine whether avoiding an AB comes at a cost. Given the non-blinkers' ability to largely avoid the occurrence of an AB, information concerning temporal order and the correct binding of features into targets might be compromised in non-blinkers. If that were indeed the case, non-blinkers should show relatively more order reversals, compared to large blinkers. However, while correcting for differences in target accuracy, the opposite pattern of results was observed. Although no significant difference in relative order reversals was found between blinkers and non-blinkers in Experiment 1b, individuals with little or no AB showed fewer rather than more order reversals than large blinkers as showed in Experiment 1a and 2. Even though the AB may have a functional role in providing episodic distinctiveness, our results suggest that avoiding an AB does not come at a cost for temporal order information.

CONCLUSIONS

By studying individual differences in response errors, we found that only a modest amount of suppression of T2 and surrounding distractors was present in blinkers. In addition, lower accuracy was closely accompanied by reduced precision during target selection in blinkers. In comparison, the temporal selection process seems to be faster and more precise in non-blinkers, and we found no evidence of suppression. Non-blinkers did show a sizeable AB when target selection was based on color features rather than alphanumeric category, but continued to outperform blinkers. Finally, we found that non-blinkers did not lack episodic distinctiveness; temporal order information was actually preserved better in individuals with a small rather than a large AB. Intriguingly, non-blinkers showed most intrusions as well as a selection delay at lag 1, a finding that deserves further investigation.

Charlotte Willems, Jefta Saija, Elkan Akyürek, and Sander Martens

THE ROLE OF TEMPORAL INTEGRATION AND ORDER REVERSALS

ABSTRACT

The reduced ability to identify a second target when it is presented in close temporal succession of a first target is called the attentional blink (AB). Studies have shown large individual differences in AB task performance, where lower task performance has been associated with more reversed order reports of both targets if these were presented in direct succession. In order to study the suggestion that reversed order reports reflect loss of temporal information, in the current study, we investigated whether individuals with a large AB have a higher tendency to temporally integrate both targets into one visual event by using an AB paradigm containing symbol target stimuli.

Indeed, we found a positive relation between the tendency to temporally integrate information and individual AB magnitude. In contrast to earlier work, we found no relation between order reversals and individual AB magnitude. The occurrence of temporal integration was negatively related to the number of order reversals, indicating that individuals either integrated or separated and reversed information.

We conclude that individuals with better AB task performance use a smaller time window to integrate information, and therefore have higher preservation of temporal information. Furthermore, order reversals observed in paradigms with alphanumeric targets indeed seem to at least partially reflect temporal integration of both targets. Given the negative relation between temporal integration and 'true' order reversals observed with the current symbolic target set, these two behavioral outcomes seem to be two sides of the same coin.

INTRODUCTION

Only a tiny part of all available visual input can be perceived consciously. The process of selection happens through allocation of attention to relevant information that is present in our surroundings. Although this system of selective attention works relatively well in most situations, if two to-be-identified targets are presented in rapid temporal succession (200-500 ms), identification of the second target nevertheless frequently fails. This cognitive limitation is called the attentional blink (AB; Raymond et al., 1992), a phenomenon that has allowed researchers to study the mechanism of temporal selective attention on the border of success and failure

INDIVIDUAL DIFFERENCES

Although the AB can be seen as fairly robust and universal (Dale & Arnell, 2013), there are large individual differences in AB task performance with some individuals even showing no AB (Feinstein et al., 2004; Martens, Munneke, et al., 2006). Studying the occurrence and nature of these individual differences can be informative about the origin of the attentional strategy that is assumed to underlie the AB. That is, rather than a structural bottleneck, the AB

has been suggested to be the result of applying a suboptimal attentional strategy (Olivers & Nieuwenhuis, 2006; Olivers et al., 2007; Taatgen et al., 2009; Wierda et al., 2010), where evidence points to a role of the distribution of attention deployed to the Rapid Serial Visual Presentation (RSVP) stream of stimuli, and the first target in particular (Arend et al., 2006; Dale & Arnell, 2014; Nieuwenstein, 2006; Olivers & Nieuwenhuis, 2005; Shapiro et al., 2006; Taatgen et al., 2009; Wierda et al., 2010, 2012). However, the exact nature of this adverse attentional strategy remains unclear.

TEMPORAL INTEGRATION

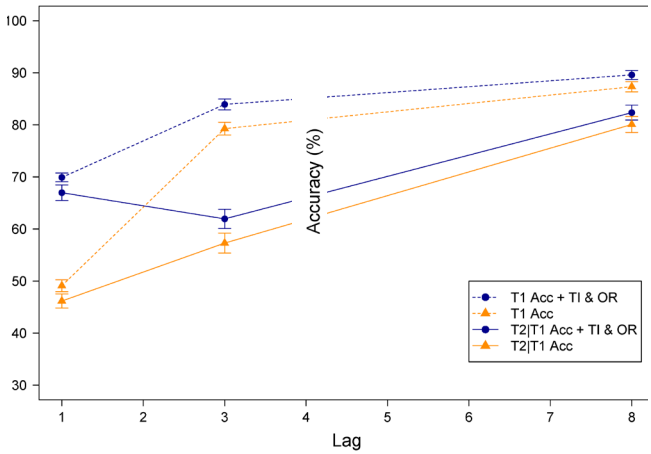
Earlier, investigating the temporal profile of individual differences in the AB, we have shown that individuals with a smaller AB magnitude show higher preservation of temporal order information, as reflected in fewer reversed order reports of T1 and T2 at lag 1 (Willems et al., 2013). As suggested by Akyürek et al. (2012), order reversals at lag 1 are at least partly determined by a mechanism of temporal integration that merges separate visual events into one single representation. They demonstrated that in an RSVP where two targets could be integrated into one visual concept, i.e., where two symbol targets could be combined into another valid symbol target (e.g., "\" and "/" form "X"), temporal integration occurred regularly at lag 1. Furthermore, the number of order reversals decreased strongly compared to a paradigm where directly reporting integrated percepts was not possible, as is the case when using alphanumerical target stimuli. This link between order reversals and integrations confirmed the idea that the order reversals seen in classic AB tasks, in which targets can typically not be reported in a combined form, principally reflect a loss of temporal information that can be attributed to integration.

The temporal window in which these visual events are integrated was furthermore found to be adaptable (Akyürek, Riddell, Toffanin, & Hommel, 2007; Akyürek, Toffanin, & Hommel, 2008). By varying stimulus presentation rate in a classic alphanumeric AB task, it was shown that the expectation of a slow presentation rate induced more temporal integration (measured indirectly with order reversal frequency), which was thought to reflect a large integration window. In contrast, the expectation of a fast presentation rate induced less temporal integration, which was thought to reflect a small integration window. The observed changes in behavior were thus interpreted as evidence for adaptive control of integration.

Following these findings, the goal of the current study is to address whether individual AB task performance is related to the individual tendency to merge two events into one single representation, i.e., the amount of temporal integration. As assumed previously, the frequency of temporal integration is taken to reflect quite directly on the size of the temporal integration window. Based on our earlier findings (Willems et al., 2013), we hypothesize that individuals with a small AB will show less temporal integration, and thus, use a smaller temporal integration window than individuals with a large AB. Furthermore, we aim to reveal the role of order reversals in relation to the occurrence of temporal integration. If order reversals in a paradigm using alphanumerical stimuli actually reflect temporal integration (Akyürek et al., 2012), then the positive relation between order reversals and AB magnitude as

Figure 4.1. The symbols that were used as target stimuli.

Figure 4.2. Mean T1 accuracy and mean T2 accuracy given that T1 was identified correctly (T2|T1) without order reversal trials or temporal integration trials (dark yellow lines). Mean T1 and T2|T1 accuracy where both order reversals and temporal integration trials are counted as correct (blue lines). The error bars reflect the standard errors of the mean.



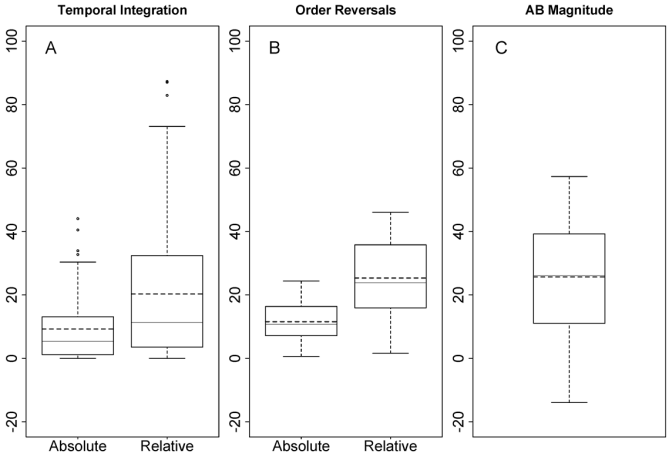


Figure 4.3. Boxplots depicting the distribution of individual differences for A) temporal integration at lag 1, B) order reversals at lag 1, and C) AB magnitude. For A) temporal integration and B) order reversals, the distribution is plotted for both the absolute and relative data. Relative is defined as trials where both target features are reported correctly, either in correct order, reversed order, or integrated. Per boxplot, the mean of the variable is indicated by the black dashed line, whereas the median is indicated by the light grey solid line.

found earlier may be absent in a paradigm where temporal integration of stimuli is possible, i.e., using symbol stimuli: This is because the remaining order reversals that are observed with such stimuli should reflect 'true' order problems, and no longer reflect integrations. In the current paradigm, these true order reversals can thus be measured directly.

METHODS

PARTICIPANTS

The Psychology Ethical Committee of the University of Groningen approved the study, and participants signed a written informed consent form before onset of the experiment. A total of 100 students participated after which they received course credits in return. The experiment was performed together with another experiment on individual differences that is reported in Willems, Herdzin, and Martens (in press). The order of both experiments was counterbalanced, and together the experiments were completed in ~90 minutes. The current experiment took ~60 minutes. Nine individuals were excluded, because T1 accuracy was < 50%, or data logging did not succeed. This left 91 participants (55 women; mean age = 20.43 years, ranging 18-29) for the final analyses.

APPARATUS AND STIMULI

The task was performed using E-prime 2.0 software, and presented in the center of a 19-inch CRT monitor with a 100 Hz refresh rate. Target stimuli were blue symbols, as shown in Figure 4.1, whereas distractor stimuli were black, 52-point Courier New, uppercase consonants, excluding "Q", "X", and "Y". The task was presented on a white background. The use of colored targets was motivated by earlier findings that task difficulty was too high when all stimuli were presented in black (Akyürek et al., 2012).

PROCEDURE

The task started with a practice block of 26 trials, which was followed by a test block of 528 trials. Each RSVP contained 19 stimuli, and was preceded by a 200-ms fixation cross. Stimulus presentation rate was 70 ms with an inter stimulus interval of 10 ms. In 504 of the 528 trials, two target symbols (Figure 4.1, symbols B-G) were presented, which could be visually combined into one symbol (symbols A-D). In 24 trials, only one target symbol was presented (symbols A-D). T1 was presented as either the fifth or the seventh stimulus in the stream. In dual-target trials, T2 was presented one, three, or eight serial positions after T1, at lag 1, 3, or 8, respectively. All lags were presented equally often. Per trial, distractor letters were pseudo-randomly selected under the constraint that successive distractor letters were never the same. In addition, target symbols were selected under the constraint that symbols were never similar within an RSVP, and that symbols with overlapping features were never presented as a pair, e.g., "/" was never presented in combination with "X". Following each RSVP, participants were prompted to enter the symbols in the order they had seen them, using a stickered numeric keyboard. Participants could indicate whether they had seen a single symbol or no symbol by pressing space bar.

STATISTICAL METHODS

Statistical analyses were performed using R (version 2.14.2, R Development Core team, 2012), and the lmerTest package (Kuznetsova, Brockhoff, & Christenen, 2013). The data were analyzed using Generalized Linear Mixed Models (GLMM), where "participants" was added as random intercept to account for repeated measures.

RESULTS

ACCURACY

Task performance is graphed in Figure 4.2. The dark yellow lines depict T1 and T2 given correct report of T1 (T2|T1) accuracy, without order reversal trials or temporal integration trials counted as correct, whereas the blue lines depict T1 and T2|T1 accuracy with both order reversals and temporal integration trials counted as correct. AB magnitude was calculated as T2|T1 accuracy at lag 3 relative to T2|T1 accuracy at lag 8, and ranged from -13.91% to 57.32% (mean = 25.66, *SE* = .13). In Figure 4.3A-C, we graphed the distribution of individual differences regarding temporal integration at lag 1 (A), order reversals at lag 1 (B), and AB magnitude (C). In Figure 4.3A-B, the distribution of order reversals and temporal integration are plotted for both the absolute and the relative data; the latter are defined as trials where both target features are reported correctly, either in correct order, reversed order, or integrated (i.e., the trials represented by the blue lines in Figure 4.2).

TEMPORAL INTEGRATION

In 9.23% (*SE* = .23) of all lag-1 trials, the symbols presented as T1 and T2 were reported as the integrated symbol for T1, and T2 was reported as being absent. For lag 3 and 8 this occurred in only .88% (*SE* = .001) and .35% (*SE* < .001) of the trials, respectively. With a GLMM with AB magnitude as fixed factor, we found that the amount of integration in lag-1 trials was significantly related to AB magnitude, β = 2.14, *SE* = 1.04, *z* = 2.05, *p* = .040. When analyzing the relation between individual AB magnitude and temporal integration in lag-1 trials relative to task performance, the predictive effect of AB magnitude was even stronger, β = 3.31, *SE* = 1.23, *z* = 2.68, *p* = .007. Given the positive direction of this relationship, depicted in Figure 4.4A and 4.4D, this finding indicates that individuals with a large AB have a higher tendency to integrate T1 and T2 at lag 1 into a single representation. In the relative data, integration occurred on 20.3% (*SE* = .48) of the lag-1 tri-

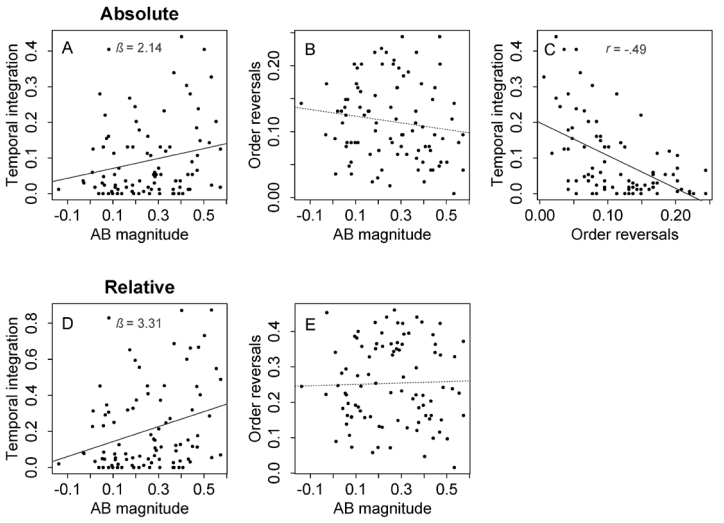


Figure 4.4. The relation between A) mean temporal integration and AB magnitude, B) mean order reversals and AB magnitude, and C) mean temporal integration and mean order reversals when taking all trials into account (A-C). The relation between D) mean temporal integration and AB magnitude and E) mean order reversals and AB magnitude in the relative data (D-E), defined as trials where both target features are reported correctly, either in correct order, reversed order, or integrated. For graphical purposes, per scatterplot a trend line was added depicting simple linear regression between the two given variables.

als, 1.7% (*SE* = .14) of the lag-3 trials, and .47% (*SE* = .06) of the lag-8 trials.

ORDER REVERSALS

For lag-1 trials, the report order of both targets was reversed in 11.55% (*SE* = .26), 3.7% (*SE* = .15) for lag-3 trials, and 1.92% (*SE* = .11) for lag-8 trials. As tested with a GLMM, we found no effect of AB magnitude on the number of order reversals in lag-1 trials (p = .10; Figure 4.4B). There was also no effect of individual AB magnitude when analyzing the occurrence of order reversals in lag-1 trials relative to task performance (p = .10, Figure 4.4E). In the relative dataset, order reversals occurred on 25.33% (*SE* = .52), 7.1% (*SE* = .29), and 2.59% (*SE* = .15) of the lag-1 trials, lag-3 trials, and lag-8 trials, respectively.

As shown in Figure 4.4C, regarding lag-1 trials, we found a negative Spearman's rank correlation between the mean number of order reversal trials and temporal integration trials (r = -.49, p < .001). This negative relation suggests that individuals who made fewer order reversals showed higher temporal integration and vice versa.

DISCUSSION

The aim of the current study was to investigate whether individual AB magnitude is related to the tendency to integrate two events that are in close temporal proximity into one event. Earlier work has shown a positive relation between AB magnitude and order reversals (Willems et al., 2013), which have been suggested to reflect the loss of temporal information (Akyürek et al., 2012). Therefore, we expected temporal integration to occur more often for large blinkers than for small blinkers, reflecting the use of a larger temporal integration window by large blinkers. Furthermore, if order reversals reflect integration of the two targets in one visual event in classic alphanumeric AB tasks (Akyürek et al., 2012), the relation between order reversals and AB magnitude may not be present in a paradigm where temporal integration of stimuli is possible, i.e., in the current experiment.

As hypothesized, we found a positive relation between AB magnitude and the amount of temporal integration at lag 1, such that a smaller AB is associated with a lower tendency to integrate information into one visual event. This effect was even stronger when analyzing the amount of temporal integration relative to task performance. We found no evidence for a relation between true order reversals and AB magnitude in either the absolute or relative dataset. Finally, we found that the occurrence of order reversals was negatively related to the amount of temporal integration, such that individuals who made more order reversals showed less temporal integration.

TEMPORAL INTEGRATION

The current findings confirm our hypothesis that small blinkers use a smaller temporal window to integrate information into one visual event, and thus, have a higher preservation of temporal information. This positive relation between temporal integration and AB magnitude fits with the distribution of erroneous responses in relation to individual AB task performance as described in (Willems et al., 2013); using a paradigm with letter stimuli only, we have found that small blinkers showed most delay - the center of mass of individual target report - at lag 1, after which the amount of delay diminished as a factor of time. In contrast, large blinkers showed the least delay at lag 1, after which delay

increased as a factor of time. When assuming that these two opposite patterns reflect the size of the applied temporal integration window, it may be that individuals have most trouble identifying T2 when it is presented just after the window in which T1 is processed, i.e., for large blinkers at lag 3 and for small blinkers at lag 1.

It is conceivable also that having a relatively long temporal integration window renders the task of identifying the targets more difficult, with increased AB magnitude as a result. Consider that at lags in which a distractor appears between targets, i.e., lag 2 and beyond, the perception of a target may suffer from the temporal proximity of the ensuing distractor. This effect may be compounded if the distractor is more likely to become part of the target event, from which position it is likely to cause more interference. Such a scenario is more likely if an observer has the tendency to use (overly) long integration windows. Further down the line, the difficulties caused by integrated-distractor interference on T1 can affect T2 also by amplifying the attentional challenges, or in other words, the AB. Previous studies on the relation between target difficulty and the AB seem to support this idea (Ouimet & Jolicœur, 2007; Seiffert & Di Lollo, 1997; Visser, 2007).

In addition, given that the size of the integration window was found to be adaptable (Akyürek et al., 2007), the finding that AB task performance is related to the size of the temporal integration window is also in line with earlier findings that the size of the AB can be manipulated by an additional distracting task (Olivers & Nieuwenhuis, 2006; Taatgen et al., 2009; Wierda et al., 2010), or diminished by training (Choi et al., 2012; Tang et al., 2013; Willems et al., 2015). Moreover, the current results indicate that individuals with a large AB are less able to preserve episodic distinctiveness than individuals with a small AB. This actually goes against the idea that the AB occurs to preserve episodic distinctiveness, as proposed by the eSTST model (Wyble et al., 2009). In addition, in this model, order reversals were subscribed to T2 entering working memory earlier than T1 due to a stronger representation and more rapid consolidation of T2 compared to T1 (Bowman & Wyble, 2007; Olivers, Hilkenmeier, & Scharlau, 2011; Wyble et al., 2009). However, given the current findings, and earlier findings of Akyürek et al. (2012), order reversals seem more likely to be the result of integration of T1 and T2 into one temporal window.

ORDER REVERSALS

In the current study, we found no relation between individual AB task performance and 'true' order reversals. These results are in line with the suggestion of Akyürek et al. (2012) that order reversals in a paradigm using alphanumerical stimuli reflect temporal integration of both targets in one visual event. Thus, given that temporal integration was possible in the current experiment, and the order reversals in this paradigm actually reflect 'true' order errors rather than integration, temporal integration trials probably took over at least part of the explained variance that is ascribed to order reversals in paradigms using alphanumerical stimuli. This might explain why we did not find a relation between order reversals and AB magnitude in the current study, whereas we did find such a relation in earlier studies using alphanumerical stimuli (Willems et al., 2013).

Regarding the observed negative relation between the number of order reversals and the

amount of temporal integration, it seems that participants either integrated or reversed information. A confound regarding this negative correlation may be that these two types of answers exclude one another. However, as can be seen in Figure 4.3A-B, temporal integration accounts for a maximum of ~40% of the trials, whereas order reversals account for a maximum of ~30%. Because these values are not at ceiling level, we think that the negative correlation can be assumed to be genuine.

In summary, we revealed that individuals with a small AB have a lower tendency to temporally integrate information into one visual representation when presented in direct succession. In addition, we found no relation between 'true' order reversals at lag 1 and AB magnitude. Evidence for a trade-off between integrations and order reversals was found instead; individuals tended to either integrate or reverse information at lag 1. Following this, we conclude that individuals with a small AB use a shorter temporal integration window than individuals with a large AB, and therefore have a higher preservation of temporal information. Furthermore, order reversals in classic AB paradigms seem to at least partially reflect temporal integration of both targets at lag 1, as was already suggested in (Akyürek et al., 2012). Given the negative relation between temporal integration and order reversals observed in the current paradigm, these two patterns of behavior seem to be two sides of the same coin.

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INDIVIDUAL DIFFERENCES IN TEMPORAL SELECTIVE ATTENTION AS REFLECTED IN PUPIL DILATION

This chapter has been published in PLoS ONE, 2015

ABSTRACT

Attention is restricted for the second of two targets when it is presented within 200-500 ms of the first target. This attentional blink (AB) phenomenon allows one to study the dynamics of temporal selective attention by varying the interval between the two targets (T1 and T2). Whereas the AB has long been considered as a robust and universal cognitive limitation, several studies have demonstrated that AB task performance greatly differs between individuals, with some individuals showing no AB whatsoever.

Here, we studied these individual differences in AB task performance in relation to differences in attentional timing. Furthermore, we investigated whether AB magnitude is predictive for the amount of attention allocated to T1. For both these purposes pupil dilation was measured and analyzed with our recently developed deconvolution method.

We found that the dynamics of temporal attention in small versus large blinkers differ in a number of ways. Individuals with a relatively small AB magnitude seem better able to preserve temporal order information. In addition, they are quicker to allocate attention to both T1 and T2 than large blinkers. Although a popular explanation of the AB is that it is caused by an unnecessary overinvestment of attention allocated to T1, a more complex picture emerged from our data, suggesting that this may depend on whether one is a small or a large blinker.

The use of pupil dilation deconvolution seems to be a powerful approach to study the temporal dynamics of attention, bringing us a step closer to understanding the elusive nature of the AB. We conclude that the timing of attention to targets may be more important than the amount of allocated attention in accounting for individual differences.

INTRODUCTION

Although human beings can extract the gist of a visual scene within a fraction of a second, they can be relatively slow to select sequentially presented relevant information from a rapid stream of irrelevant information. That is, attention to relevant information is restricted for the second of two targets when it is presented within 200-500 ms of the first target. This phenomenon, known as the attentional blink (AB; Raymond et al., 1992), allows one to study the dynamics of temporal selective attention by systematically varying the interval between the two targets (T1 and T2). Recent evidence suggests that the AB is due to the default use of an adverse attentional strategy (Di Lollo et al., 2005; Olivers & Nieuwenhuis, 2006; Olivers et al., 2007; Taatgen et al., 2009; Wierda et al., 2010), but the precise nature of this problem to control attention remains unclear.

To shed light on this underlying mechanism of the AB, one can study the origin of individual differences in AB task performance; although the AB was initially considered to reflect a universal, fundamental attentional restriction, large differences in individual AB task performance have been revealed over the past years (Arnell et al., 2006; Colzato et al., 2007; Martens, Elmallah, et al., 2006; Martens et al., 2009; Martens, Munneke, et al., 2006; McArthur et al., 1999; McLaughlin et al., 2001). In these studies, individual AB task performance has been investigated in relation to a variety of factors, e.g., other cognitive tasks (Arnell et al., 2010; Colzato et al., 2007; Klein et al., 2011), personality characteristics (MacLean et al., 2010; Troche & Rammsayer, 2013), and lifestyle (Green & Bavelier, 2003; van Vugt & Slagter, 2014), either within a large group of participants (Dux & Marois, 2008; MacLean et al., 2012; McArthur et al., 1999; Willems et al., 2013), or by contrasting performance of two extreme groups, i.e., blinkers vs. non-blinkers (Feinstein et al., 2004; Martens, Munneke, et al., 2006).

TIMING ATTENTION

One difference underlying individual AB task performance may be the timing of attention allocated to the targets as presented in the rapid serial visual presentation (RSVP) stream. Although processing speed per se has not been found to be a predictive factor for individual AB magnitude (McLean et al., 2009; Visser & Ohan, 2012), studies have revealed individual differences in attentional timing in the AB paradigm; as indicated by the event related potential component P3 in trials where both targets were identified correctly, i.e., no-blink trials, it was revealed that non-blinkers are earlier in updating the content of working memory (WM) than blinkers, irrespective of lag or target (Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013). In addition, it was found that individuals with a higher rate of WM updating showed a larger AB magnitude (Slagter et al., 2012). Furthermore, we have shown that the size of the AB was predictive for the precision of target selection (Willems et al., 2013). That is, in an AB task where the stream of stimuli contained letters only, and targets and distractors had to be distinguished based on color, small blinkers selected items that were close to the actual target whereas the selection pattern was more diffused for large blinkers. Here, we also revealed that a smaller AB magnitude is related to better preservation of temporal order information, as reflected in fewer reversed order reports of T1 and T2 (Willems et al., 2013).

To reveal the temporal dynamics of attentional allocation in the AB paradigm, we have recently focused on pupil dilation as a measure of attentional timing and cognitive workload (Wierda et al., 2012). However, because the pupil response takes ~1 sec, responses to stimuli in a fast-paced task like the AB task are overlapping, and any meaningful differences remain concealed. Therefore, the pupil dilation deconvolution method was developed, which allows one to isolate and track the temporal dynamics of target-related attentional allocation (Wierda et al., 2012). Because the total pupil response to the RSVP stream is assumed to be the sum of all separate responses to the stimuli (Hoeks & Levelt, 1993), the signal can be deconvolved to single pulses related to attention allocated to the presented stimuli (Wierda et al., 2012). Earlier, using the pupil dilation deconvolution method to track training-induced changes in attentional allocation, we already found that better task performance in the AB

paradigm was related to earlier attentional allocation to T2, but there was no such evidence for T1 (Willems et al., 2015).

In the current study, the first aim is to reveal the time course of attentional allocation in the AB paradigm in relation to individual AB magnitude. By analyzing reversed order reports of T1 and T2, we will test whether we can replicate our earlier findings that better preservation of temporal order information is related to a smaller AB magnitude (Willems et al., 2013). Moreover, by measuring pupil dilation, we will focus on differences in attentional timing to the targets in relation to individual AB task performance. Because small blinkers appear to be earlier in WM updating (Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013), and more efficient in target selection (Visser & Ohan, 2012; Willems et al., 2013), we hypothesize that earlier allocation of attention will be related to a smaller AB magnitude. In the deconvolved pupil data, this would result in earlier peaks of the pulses reflecting attentional allocation to the targets. Based on our previous pupil dilation study (Willems et al., 2015), we expect that this relation between earlier attentional allocation and better AB task performance will be most pronounced for T2.

OVERINVESTMENT OF ATTENTION

Next to timing, the strength of attentional investment can also be studied by measuring pupil dilation. In previous studies, it has been argued that one aspect of the detrimental strategy that presumably causes the AB is attentional overinvestment to T1 (Olivers & Nieuwenhuis, 2005, 2006; Shapiro et al., 2006). That is, if cognitive control is deployed too stringent towards target selection, an overly strong focus on selecting the first target is likely to come at a cost for selecting the second target during the AB period. This theory was supported by earlier pupil dilation studies, where the attentional response to T1 was found higher in blink trials than in no-blink trials (Wierda et al., 2012; Willems et al., 2015). Further evidence was obtained in an EEG study, reporting a higher P3 amplitude in blink trials than in no-blink trials (Martens, Elmallah, et al., 2006). However, these studies found no relation between individual AB task performance and attentional investment to T1 (Martens, Elmallah, et al., 2006; McArthur et al., 1999; Willems et al., 2015). In contrast, though, both an fMRI and a MEG study showed that higher activation related to T1 encoding was linked to lower individual T2 accuracy (Shapiro et al., 2006; Slagter et al., 2010).

To resolve these somewhat mixed findings, the second goal of this study is to examine the amount of attention allocated to the targets, as indicated by the deconvolved pupil signals. Hereby, we aim to reveal whether any attentional overinvestment to T1 is related to individual AB task performance. It is expected that attentional overinvestment to T1 will result in higher T1 amplitudes of the deconvolved pulses in blink trials compared to no-blink trials. In addition, if any attentional overinvestment is related to individual AB magnitude, a larger AB magnitude is expected to be related to a larger attentional response to T1.

In summary, the aim of the current study is twofold: First, we aim to reveal the time course of individual attentional deployment in the AB paradigm. Second, we will investigate whether AB magnitude is predictive for the amount of attention allocated to T1. For both these purposes pupil dilation will be measured.

METHODS

PARTICIPANTS

The study was approved by the Psychology Ethical Committee of the University of Groningen, and participants signed a written informed consent form prior to the experiment. In total, 100 students performed the experiment for which they received course credits in return. The experiment was performed together with an experiment on temporal integration that will be reported elsewhere. The order of these two experiments was counterbalanced, and together, these experiments were completed in ~90 minutes. The duration of the current experiment was ~30 minutes. After initial data screening, ten participants were excluded, because either T1 accuracy was < 50%, or data logging went wrong. Regarding the analyses of the pupil data, another nine participants were excluded, because the pupil data contained too many artifacts - more than one third of the trials had to be discarded - or pupil measurement did not succeed. This left 90 participants (55 women; mean age = 20.45, ranging 18-29) for the behavioral analyses, and 81 participants (52 women; mean age = 20.48, ranging 18-29 years) for the pupil analyses.

APPARATUS AND STIMULI

The experiment was generated and recorded by E-prime 2.0 software, and presented in the middle of a 19-inch CRT monitor with a 100 Hz refresh rate. Target stimuli were uppercase consonants, excluding "Q", "X", and "Y", whereas distractor stimuli were digits, excluding "0" and "1". Stimuli were presented in black, 18-point Courier New on a white background. Pupil size was measured using the EyeLink 1000 eye-tracker (www.sr-research.com) at a sampling rate of 250 Hz. Participants kept their head in a chin-rest during the experiment and viewing distance was ~50 cm.

PROCEDURE

The experiment contained a practice block of 20 trials, and a test block of 196 trials. Each trial started with a fixation cross of 1000 ms, followed by an RSVP of 32 stimuli (~10 Hz). In 168 of the 196 trials, the RSVP stream contained two target letters, i.e., dual-target trials, whereas in 28 trials, only one letter was presented, i.e., single-target trials. Taking these rates into account, trials were presented randomly with the additional constraint for dual-target trials that each lag was presented equally often. T1 was always the sixth item in the stream, which was chosen to allow for a consistent response to the first target, reducing unnecessary variability in behavioral performance and pupil dilation responses. In dual-target trials, T2 was presented as the first, third, or eighth item after T1, lag 1, 3, and 8, respectively. Stimuli were chosen randomly under the prerequisite that a target letter was never repeated within one trial, and that successive distractor digits were never the same. The RSVP was followed by either a 100-ms dot or comma, which had to be identified in addition to the target letters. This comma/dot task was included to encourage participants to remain fixated to the center of the screen throughout stimulus presentation, allowing optimal measurement of the pupil response to both targets. After each RSVP stream, participants where prompted to enter the target letters in the order they had seen them, using the corresponding keys on the keyboard, and to enter whether they had seen a comma or a dot. When a single or no letter was seen, participants could indicate this by pressing the space bar.

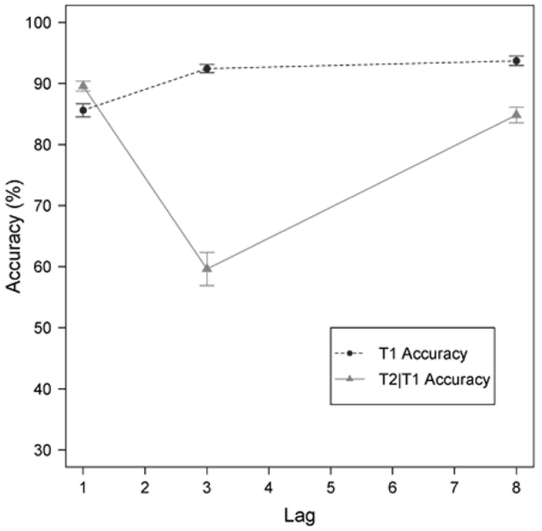


Figure 5.1. Mean T1 accuracy and mean T2 accuracy assumed that T1 was identified correctly (T2|T1). The error bars reflect the standard errors of the mean.

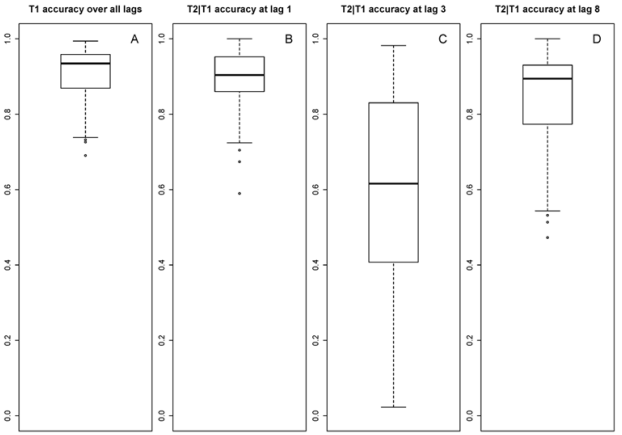


Figure 5.2. Boxplots depicting the distribution of individual differences in the AB letter-digit task A) for mean T1 accuracy over all lags (lag 1, 3, and 8), and for mean T2|T1 accuracy at B) lag 1, C) lag 3, and D) lag 8.

PRE-PROCESSING PUPIL DATA

The pupil data were down-sampled to 50 Hz and time-locked to the onset of T1. The average pupil size in the 200 ms preceding the stream was used as baseline, and data were normalized by subtracting the baseline from the measured size and by dividing this value by the baseline. With the pupil dilation deconvolution method (Wierda et al., 2012), per combination of participant and condition, 80 pulses were modeled, starting 260 ms before stream onset. The set of pulse strengths i was convolved with the Erlang gamma function $h = s * t\,(n) * (\frac{-n*t}{t_{max}})$, where s is a scaling factor, n is the number of layers, and t_{max} is the position of the maximum response. These parameters were set to n = 10.1, t_{max} = 930 and s = 1/1027 (Wierda et al., 2012). The pulse strengths were obtained by optimizing the fit between the estimated signal and the measured pupil dilation signal, where l is the position of each pulse in vector i and b controls for linear drifts in the data. As in (Willems et al., 2015), we used an inter-pulse interval of 50 ms, and the Levenberg-Marquardt algorithm for optimizing the strengths of the attentional

pulses. Segments containing eye blinks were semi-automatically corrected using linear interpolation or discarded.

The latency of the pulse associated with T1 was determined by calculating the first local peak within a time window ranging -100 to 500 ms relative to the onset of T1. For T2, the latency was determined by calculating the local peak within a time frame ranging 500 to 1100 ms for lag 3, and 1000 to 1600 ms for lag 8, relative to the onset of T1. The average strength of the pulse preceding and the pulse following the local peak, and the local peak itself were used as a measure of amplitude.

STATISTICAL METHODS

Statistical analyses were performed using R (version 2.14.2, R Development Core team, 2012). With the *lmerTest* package (Kuznetsova et al., 2013), behavioral data were analyzed with generalized linear mixed models (GLMM) and pupil dilation data with either linear mixed models (LMM) or, in case of no repeated measures, linear models (LM). To account for repeated measures, "participants" was entered in all mixed models as random intercept, and in case of overdispersion, an observation-level random intercept was added to the model. Continuous factors were standardized by subtracting the column means, and dividing these centered values by their standard deviations. Unless mentioned otherwise, fixed factors and interaction terms were included based on model comparisons using analyses of variance (ANOVA). To avoid collinearity between fixed factors, we tested different measures of AB task performance in different models. Covariance structures were modeled using the nlme package (Pinheiro, Bates, DebRoy, Sarkar, & R Development Core team, 2012) and compared using the Akaike information criterion (Akaike, 1974). This comparison revealed that in all cases the structure with the assumption that there are no within-group correlations fitted best.

RESULTS

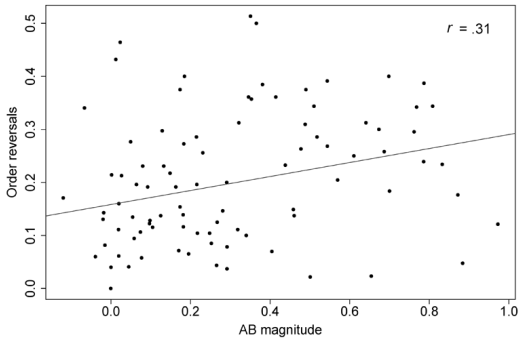
BEHAVIORAL

The behavioral results for T1, and T2 given correct report of T1 (T2|T1) are graphed in Figure 5.1. Mean T1 accuracy was 85.62% at lag 1, 92.44% at lag 3, and 93.71% at lag 8, and individual mean T1 accuracy over these lags ranged from 69.05% to 99.40%. The distribution of individual differences for mean T1 accuracy is displayed in the boxplot in Figure 5.2A. T1 accuracy was found to differ significantly between lag 1 and 3, β = .77, *SE* = .07, z = 11.18, p < .001; lag 1 and 8, β = .98, *SE* = .07, z = 13.44, p < .001; and lag 3 and 8, β = .21, *SE* = .08, z = 2.57, p = .010. Single-target accuracy was 94.25%.

Mean T2|T1 accuracy was 90.03% at lag 1, 60.25% at lag 3, and 85.43% at lag 8. Individual T2|T1 accuracy at lag 3, thus, within the AB period, ranged from 2.27% to 98.21%. The distribution of mean individual T2|T1 accuracy per lag is graphed in Figure 5.2B-D. T2|T1 accuracy differed significantly between lag 1 and 3, β= -1.97, *SE* = .06, z = -31.40, p < .001; lag 1 and 8, β = -.44, *SE* = .07, z = -6.42, p < .001; and lag 3 and 8, β = 1.53, *SE* = .05, z = 27.97, p < .001. Trials where T1 and T2 were identified correctly, but reported in reversed order, were also counted as correct.

To determine AB magnitude, we calculated AB magnitude relative to mean T1 performance (meanT1 – $T2|T1_{lag3}$ / meanT1), as well as AB magnitude relative to T2|T1 at lag 8 ($T2|T1_{lag8}$

Figure 5.3. Scatterplot depicting the relation between AB magnitude and the number of reversed order reports of T1 and T2 per individual in lag-1 no-blink trials. The line depicts a simple linear regression line between AB magnitude and order reversals. The correlation presented is a Spearman Rank Correlation Coefficient.



– $T2|T1_{lag3}$ / $T2|T1_{lag8}$). AB magnitude relative to mean T1 ranged from -.002 to .97 (μ = .35, *SE* = .002), whereas AB magnitude relative to lag-8 T2|T1 accuracy ranged from -.12 to .97 (μ = .31, *SE* = .002). Because these two measures correlated highly (Pearson's r = .96, p < .001), we will only report the effects of AB magnitude relative to lag-8 T2|T1 accuracy (MacLean & Arnell, 2012).

Given trials in which both targets were identified correctly, we found that in 19.59% (*SE* = .63) of the lag-1 trials, targets were reported in reversed order. For lag 3, this was 2.89% (*SE* = .32), and for lag 8, this was .45% (*SE* = .10). As tested with a GLMM, the number of order reversals in lag-1 trials where both T1 and T2 were reported correctly could be predicted by AB magnitude, β = .23, *SE* = .08, z = 2.73, p = .006. Thus, as shown in Figure 5.3, we found that a smaller AB magnitude was associated with fewer order reversals of T1 and T2.

PUPIL DILATION

The deconvolved pupil data for lag 3 and 8 in either blink or no-blink trials are depicted in Figure 5.4A-C. Here, for graphical purposes the sample was divided in two groups based on the median AB magnitude: small blinkers vs. large blinkers. However, the analyses were performed with AB magnitude as a continuous variable (Preacher et al., 2005). For the deconvolved pulses associated with attentional allocation to the targets, we tested to which extent latency and amplitude could be predicted by AB task performance. All analyses were performed under the prerequisite that T1 was reported correctly. Furthermore, in analyses regarding lag-8 trials or pulses associated with T2, we only analyzed no-blink trials.

T1 Latency. For lag-3 trials, in an LMM with AB magnitude and blink/no-blink trials as predictive factors, we only found a trend that AB magnitude was predictive for T1 latency, β = .14, *SE* = .07, t = 1.84, p = .068. Furthermore, there was no evidence that T1 latency differed between blink and no-blink trials (p = .18). However, when analyzing no-blink trials only, AB magnitude could predict T1 latency as tested with an LM, β = .25, *SE* = .10, t = 2.51, p = .015, but this was not the case when testing blink trials only (p = .76). Thus, individuals with a relatively small AB seem quicker to allocate attention to T1 in no-blink trials than individuals with a relatively large AB, but AB magnitude was not found to be related to T1 latency in blink trials.

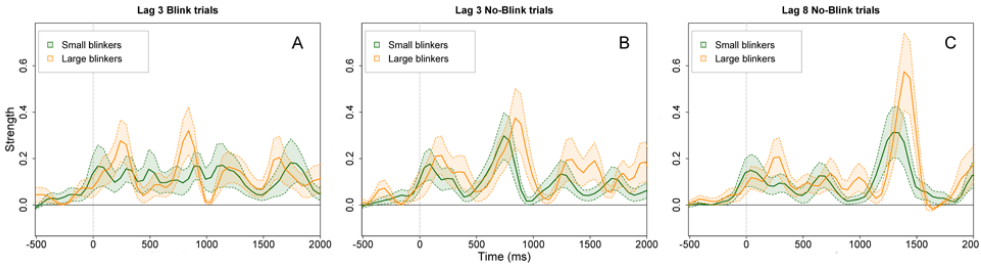


Figure 5.4. The mean strength of the deconvolved attentional pulses for small blinkers and large blinkers. For graphical purposes, the sample is divided in two groups based on the median AB magnitude. A) Lag-3 blink trials, i.e., T2 was identified incorrectly, B) Lag-3 no-blink trials, i.e., T2 was identified correctly, and C) Lag-8 no-blink trials. The depicted signal was smoothed with a Butterworth filter, and the x-axis was time-locked to the onset of T1. The error bars reflect the standard errors of the mean.

In another LMM for lag-3 trials with mean T1 accuracy over all lags and blink/no-blink trials as fixed factors, mean T1 accuracy was predictive for T1 latency, β = -.24, *SE* = .08, *t* = -3.16, *p* = .002, such that higher mean T1 accuracy was associated with earlier allocation of attention to the first target. Again, there was no effect of blink/no-blink trials (*p* = .19). When analyzing no-blink trials and blink trials separately, an LM showed an effect of mean T1 accuracy over all lags in both no-blink trials, β = -.26, *SE* = .11, *t* = -2.39, *p* = .019; and in blink trials, β = -.23, *SE* = .11, *t* = -2.09, *p* = .040. Thus, mean T1 accuracy over all lags seems predictive for the timing of attention to T1 irrespective of T2 accuracy.

Regarding lag-8 trials, there was no evidence that T1 latency was related to AB magnitude, or mean T1 accuracy over all lags, as tested in two separate LMs (*ps* > .14). In addition, after visible inspection of the data (Figure 5.4C), we re-determined T1 latency in lag-8 trials using the local peak method instead of the first local peak method, as described in the method section. However, using the local peak method, there were also no significant effects of AB magnitude or mean T1 accuracy (*ps* > .17). Therefore, the relation between the timing of attention allocated to T1 and AB task performance seems apparent in lag-3 trials, i.e., during the blink period, but not at the longer lag.

T2 Latency. In lag-3 no-blink trials, as tested in two LMs, we found that both AB magnitude, β = .23, *SE* = .10, *t* = 2.25, *p* = .027; and mean T2|T1 accuracy at lag 3, β = -.25, *SE* = .10, *t* = -2.42, *p* = .018, were predictive for the timing of attention to T2. Furthermore, for lag-8 trials, T2 latency was also related to both AB magnitude, β = .25, *SE* = .09, *t* = 2.81, *p* = .006; and mean T2|T1 accuracy at lag 8, β = -.55, *SE* = .07, *t* = -7.70, *p* < .001. Thus, as can be seen in Figure 5.4B-C, individual AB task performance is reflected in the timing of attention to T2 in no-blink trials, such that better AB task performance predicts earlier allocation of attention to T2, irrespective of lag.

Delay. We tested whether the delay, defined as the time differ-

[1] *One data point was removed from the analyses concerning T1 amplitude at lag 3, because the strength of this pulse associated with T1 processing deviated more than three standard deviations from the mean.*

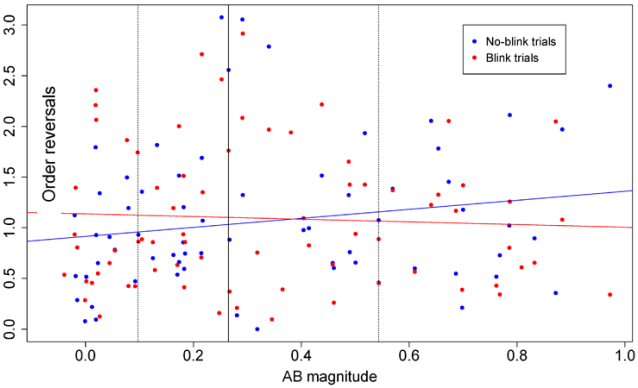


Figure 5.5. Scatterplot depicting the interaction between AB magnitude and blink/no-blink trials for T1 amplitude in lag-3 trials. The vertical lines represent the quartiles of AB magnitude, where the solid vertical line represents the median AB magnitude.

ence between the target onset and the local peak, differed between T2 and T1 in no-blink trials. For lag-3 trials, the delay was larger for T2 (mean = 441.27 ms, *SE* = 14.50) than for T1 (mean = 132.86 ms, *SE* = 15.00), β = 1.5, *SE* = .08, *t* = 18.16, *p* < .001; as was also the case for lag-8 trials (T1: mean = 162.08 ms, *SE* = 17.62; T2: mean = 493.09 ms, *SE* = 11.30), β = 1.61, *SE* = .10, *t* = 16.87, *p* < .001. These results indicate that the extra load of T2 processing on top of T1 processing causes a delay in the speed with which attention can be allocated to the targets.

T1 Amplitude. For the analyses regarding T1 amplitude, we included in all models the two-way interaction term, because we set a-priori hypotheses about possible interactions between AB task performance and blink/no-blink trials. First, we analyzed the strength of T1 pulses at lag 3[1] with an LMM with AB magnitude, blink/no-blink trials, and their two-way interaction term as fixed factors. Here, we found no unconditional main effect of AB magnitude or blink/no-blink trials (*ps* > .58), but there was a just significant interaction between AB magnitude and blink/no-blink trials, β = .21, *SE* = .10, *t* = 2.00, *p* = .049. This interaction is displayed in Figure 5.5, where it can be seen that small blinkers invest more attention in T1 in blink trials than in no-blink trials, but that for large blinkers this pattern is the other way around. However, a separate LM with AB magnitude as predictive factor for T1 amplitude in blink trials only did not reveal an effect of AB magnitude, β = -.05, *SE* = .11, *t* = -.45, *p* = .65. In addition, the same model for no-blink trials also showed no effect of AB magnitude, β = .16, *SE* = .11, *t* = 1.46, *p* = .15. Thus, the negative relation between AB magnitude and attentional investment in T1 in blink trials differs from the positive relation in no-blink trials, but the slopes per se were not significant. An LMM with mean T1 accuracy, blink/no-blink trials, and their interaction term did not reveal any significant effects (*ps* > .11).

T2 Amplitude. We found no evidence that T2 amplitude at lag 3 could be predicted by AB magnitude or by mean T2|T1 accuracy at lag 3 (*ps* > .72). In addition, there was no effect of AB magnitude or mean T2|T1 accuracy at lag 8 with regard to T2 amplitude at lag 8 (*ps* > .40).

DISCUSSION

The current study covered two goals that were both investigated by measuring pupil dilation. First, we aimed to reveal the time course of attentional allocation in the AB task in relation to individual AB magnitude. Behaviorally, we hypothesized that individuals with a smaller AB magnitude would maintain higher preservation of temporal order information (Willems et al., 2013). Regarding pupil dilation, small blinkers were expected to allocate attention earlier in time to the targets, because they seem to be more efficient in target selection (Visser & Ohan, 2012; Willems et al., 2013), and earlier in WM updating (Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013). Second, based on the theory of attentional overinvestment to T1 as underlying the AB (Olivers & Nieuwenhuis, 2005, 2006; Shapiro et al., 2006), we tested whether individual AB task performance is related to the amount of attention invested in selection of T1. We expected that attentional overinvestment to T1 would result in higher T1-elicited amplitudes in blink trials than in no-blink trials. Furthermore, if attentional overinvestment would be related to individual AB task performance, individuals with a relatively large AB magnitude should also show a larger attentional response to T1 compared to small blinkers.

In a sample of 90 participants, we found large differences in individual AB task performance of which the distribution is graphed in the boxplots in Figure 5.2A-D. Furthermore, we found that a smaller AB magnitude was related to fewer reversed order reports of the targets in lag-1 no-blink trials. In the pupil data, we found for lag 3 that timing of attention to T1 could be predicted by both AB magnitude and mean T1 accuracy in no-blink trials, but only by mean T1 accuracy in blink-trials. For lag 8, attentional timing to T1 was not related to AB task performance. Timing of attention to T2 could be predicted by AB task performance irrespective of lag. Regarding attentional overinvestment in T1, we found an interaction between blink/no-blink trials and AB magnitude. That is, a larger AB magnitude was related to higher attentional investment in no-blink trials than in blink trials, whereas this pattern was the other way around for small blinkers. When analyzing blink and no-blink trials in separate models, there was in both cases no effect of AB magnitude.

TIMING OF ATTENTION

Behaviorally, we revealed that a smaller AB magnitude is related to higher preservation of temporal order information regarding T1 and T2. This replicated an earlier study (Willems et al., 2013), where we also showed a positive relation between AB magnitude and the number of reversed order reports. These results refute the theory of Wyble et al. (2009) that the AB can be seen as a cognitive strategy that enforces episodic distinctiveness between successive stimuli. According to this theory, a smaller AB would result in more order reversals, because episodic distinctiveness would be lower for these individuals. However, we observed the exact opposite pattern in the current study and in Willems et al. (2013). As suggested by Akyürek et al. (2012), order reversals at lag 1 might reflect a mechanism of temporal integration, where targets are integrated into one temporal event when they are presented in close temporal succession. Given that large blinkers make more order reversals, they may also be more prone to integrate information than small blinkers. Future research is needed to investigate this idea in closer detail.

By measuring pupil dilation, we showed that when both targets are identified correctly, timing of attention to T2 could be predicted by either AB magnitude or target accuracy at the tested lag. That is, individuals with a relatively small AB magnitude were quicker to allocate attention to T2 than individuals with a large AB magnitude. This finding is in line with earlier pupil dilation findings where attentional timing to T2 was also related to mean T2|T1 accuracy in no-blink trials (Willems et al., 2015). Furthermore, in EEG studies, the P3 component was found to peak earlier for non-blinkers than for blinkers in no-blink trials regardless of target and lag (Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013). Therefore, it seems that earlier allocation of attention in response to T2 is beneficial for general AB task performance. However, whether this earlier timing of attention is due to faster allocation of attention, better preparation of the attentional system, or both remains to be clarified in further research.

For T1, the relation between attentional timing and AB task performance seems to be somewhat less consistent. For the short lag, both mean T1 accuracy over all lags and AB magnitude could predict attentional timing to T1 in no-blink trials, but only mean T1 accuracy was related to attentional timing to T1 in blink trials. These findings suggest that identification of T1 is dependent on the timing of attention to the first target irrespective of T2 identification. However, in no-blink trials, earlier timing of attention to T1 is also predictive for a smaller individual AB magnitude. If the second target is not identified correctly, or presented at lag 8, the timing of T1-allocated attention could no longer be linked to AB magnitude. It must be noted that this latter finding may be due to higher variability of attentional timing to T1 in blink lag-3 trials and no-blink lag-8 trials. That is, because in these trials T2 is either missed or presented at the long lag, timing to T1 is less crucial, i.e., resulting in a mixture of trials on which participants are either early or late in allocating attention to T1. In no-blink lag-3 trials, late allocation will have more consequences for T2 performance and will often result in missing T2, thus, resulting in less variability in attentional timing. This increased variability in blink lag-3 trials and no-blink lag-8 trials may explain why tests remained non-significant despite visual inspection of Figure 5.4A and 5.4C suggesting otherwise.

In an earlier pupil dilation study, we did not find any evidence for a relation between the timing of attention to T1 and AB task performance (Willems et al., 2015). It must be noted, though, that these analyses comprised both blink and no-blink trials, which in this study also resulted in only a trend for AB magnitude. Given that EEG studies did find an earlier peak of the T1-elicited P3 for non-blinkers than for blinkers (Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013) in no-blink trials, the relation between attentional timing to T1 and individual AB task performance remains subject for further research. However, the current evidence suggests that earlier attentional allocation to T1 can at least be predicted by AB magnitude in short-lag no-blink trials.

Finally, we found a difference between T1 and T2 in the delay of attentional timing to the targets defined as the difference between target onset and the peak associated with attentional allocation to the target. The delay of attentional timing to the targets was found to be larger for T2

than for T1 at both lag 3 and 8 no-blink trials, which suggests that the additional processing of T2 on top of T1 processing increases the workload, and causes a delay in the timing of attention allocated to T2. This is in line with previous studies reporting WM consolidation to be delayed for T2 compared to T1 (Martens, Munneke, et al., 2006; Vogel & Luck, 2002).

OVERINVESTMENT OF ATTENTION

We found that the pattern for attentional investment in T1 differs in relation to individual AB magnitude, such that small blinkers invested more attention in blink trials than in no-blink trials, and that large blinkers invested more attention in no-blink trials than in blink trials. However, AB magnitude was not found to be predictive for T1 amplitude in either blink trials or no-blink trials when tested separately. Several earlier studies have revealed evidence for the existence of attentional overinvestment as an aspect underlying the AB (Olivers & Nieuwenhuis, 2005, 2006; Shapiro et al., 2006). However, based on these results, large blinkers in particular would be expected to invest more attention in T1 in blink trials than in no-blink trials. However, we found this expected pattern only for the relatively small blinkers, and the exact opposite pattern for large blinkers. It remains unclear why these specific patterns were found. In earlier studies measuring pupil dilation, and using the pupil dilation deconvolution method, we did find significant differences in amplitude for the T1 pulse between blink trials and no-blink trials (Wierda et al., 2012; Willems et al., 2015), suggesting that the technique itself is sensitive enough to detect differences in attentional investment. Note also that we tested a large sample of participants with a classic AB paradigm which resulted in the typical hook-shaped AB pattern, as can be seen in Figure 5.1.

Finally, it should be noted that a potential limitation of the individual differences approach is that the proportion of blink/no-blink trials is different for participants who performed well in the AB task versus participants who performed less optimal. To alleviate the influence of this possible confound, we tested both a large sample of 80 participants and a reasonable number of 56 trials per lag. Furthermore, we used a robust analyzing technique, i.e., linear mixed models, that can handle potential differences in variance.

CONCLUSION

Based on the current findings, we conclude that there is a negative relationship between AB magnitude and preservation of temporal order information, such that small blinkers seem better able to preserve temporal order information. Furthermore, in trials during which both targets are successfully identified, faster attentional allocation to T2 is predictive for better AB task performance. The relation between attentional timing to T1 and individual AB task performance was less consistent across conditions, but earlier attentional allocation to T1 could at least be predicted by AB magnitude in short-lag no-blink trials. Finally, we did not find evidence for the idea that large blinkers tend to invest more attention to T1 than small blinkers. Therefore, it seems that timing of attention rather than the amount of allocated attention to targets is the most important factor to account for individual differences in the AB.

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Shared first authorship by Charlotte Willems and Atser Damsma

TRAINING-INDUCED CHANGES IN THE DYNAMICS OF ATTENTION AS REFLECTED IN PUPIL DILATION

This chapter has been published in Journal of Cognitive Neuroscience, 2015.

ABSTRACT

One of the major topics in attention literature is the attentional blink (AB), which demonstrates a limited ability to identify the second of two targets (T1 and T2) when presented in close temporal succession (200-500 ms). Given that the effect has been thought of as robust and resistant to training for over two decades, one of the most remarkable findings in recent years is that the AB can be eliminated following a one-hour training with a color-salient T2. However, the underlying mechanism of the training effect as well as the AB itself is as of yet still poorly understood.

To elucidate this training effect, we employed a refined version of our recently developed pupil dilation deconvolution method to track any training-induced changes in the amount and onset of attentional processing in response to target stimuli. Behaviorally, we replicated the original training effect with a color-salient T2. However, we showed that training without a salient target, but with a consistent short target interval is already sufficient to attenuate the AB. Pupil deconvolution did not reveal any post-training changes in T2-related dilation, but instead an earlier onset of dilation around T1. Moreover, normalized pupil dilation was enhanced post-training compared to pre-training.

We conclude that the AB can be eliminated by training without a salient cue. Furthermore, our data point to the existence of temporal expectations at the time points of the trained targets post-training. Therefore, we tentatively conclude that temporal expectations arise as a result of training.

INTRODUCTION

In daily situations such as driving in heavy traffic or playing sports, the right timing of attentional allocation can be crucial. Unfortunately, mistakes are hard to prevent, because attentional allocation is not solely under conscious control. A phenomenon that presumably arises from this failure to control attention is the attentional blink (AB): the limited ability to identify the second of two targets when they are presented in close temporal succession (200-500 ms) (Raymond et al., 1992). Despite two decades of research, no consensus has yet been reached on whether the AB originates from a limitation of resources (Chun & Potter, 1995; Dell'Acqua et al., 2009; Dux et al., 2008; Shapiro et al., 1994) or is a detrimental side effect of an attentional strategy (Nieuwenstein et al., 2005; Nieuwenstein & Potter, 2006; Olivers et al., 2007; Taatgen et al., 2009; Wyble et al., 2009). On either side of the discussion, though, the AB has been thought of as robust and resistant to training (Braun, 1998; Dale & Arnell, 2013; Maki & Padmanabhan, 1994; Taatgen et al., 2009, for reviews see: Dux & Marois, 2009; Martens & Wyble, 2010). In contrast to this view, a recent study has revealed that

the AB can be eliminated by only one hour of training using a color-salient second target consistently presented at short time intervals (Choi et al., 2012). However, the underlying cause of this training-induced improved performance remains as of yet still unknown.

According to Choi et al. (2012), this enhanced temporal resolution might be the result of a fundamental improvement which could be due to either top-down attentional processes or increased processing abilities. Choi and colleagues found that the training effect was generalizable to multiple time intervals between the targets, i.e., lags, and persisted up to several months. In addition, performance was improved on a different, target-mask task with only a single target. They argued that the increased temporal resolution is most likely the result of fundamental attention-based improvements. This claim is supported by evidence from an fMRI experiment in which Choi et al. found differences in dorsolateral prefrontal activity when comparing target processing at short lags with target processing at long lags post-training. According to Choi et al., if the training induced a general enhancement in target processing, such differences would not be observed. It is questionable though how strong the neuroimaging evidence supports this claim, given the limited temporal resolution of fMRI.

In contrast, Tang, Badcock, & Visser (2013) suggested that the effect of training is due to the strengthening of temporal expectations that arise from the fixed temporal locations of the targets during the training. This theory was evidenced by their finding that the training effect could be reduced by diminishing the temporal expectations with a more variable task or training. Furthermore, they found a decrease in performance at the longer lag after the color-salient training, but an attenuation of this performance decrease at the longer lag after the variable task condition and the variable training condition. Because the color-salient training consisted of short-lag trials only, Tang et al. argued that the timing of the targets was trained as opposed to the explanation that a fundamental change in target processing had occurred (Choi et al., 2012). However, the temporal expectations account can neither explain why the effect of training was generalizable to multiple lags and another task (Choi et al., 2012), nor can it exclude that a variable training or task just needs a longer training duration to attain a similar improvement in performance.

In order to resolve these issues, we aimed to study training-induced changes in attentional allocation by measuring pupil dilation. Pupil dilation is thought to reflect changes in activity of the Locus Coeruleus (LC): a nucleus which is the hub of the noradrenergic system (for reviews see: Laeng, Sirois, & Gredebäck, 2012; Sara, 2009). Given that phasic activity of the LC is associated with the processing of task-relevant stimuli (Aston-Jones & Cohen, 2005; Dayan & Yu, 2006), task-evoked pupil dilation is thought to reflect changes in the attentional detection system (Privitera, Renninger, Carney, Klein, & Aguilar, 2008). Although pupillary responses have a delay of ~1 sec, it is possible to analyze a fast-paced task like the AB task (~10Hz) by using our recently developed pupil dilation deconvolution method (Wierda et al., 2012). This method assumes that the pupillary response reflects a summation of responses to separate events (Hoeks & Levelt, 1993), which makes it possible to deconvolve the pupil dilation signal into isolated attentional pulses that are associated

with the processing of each of the two targets. A benefit of this deconvolution method is that it allows for the extraction of expectation effects, which can arise in the absence of an actual target (Wierda et al., 2012).

Using a refined version of this deconvolution method, our goal in the current paper is to address the changes in target-related attentional allocation as a result of the color-salient training. Two additional training tasks will function as control conditions, which leaves us with three training conditions: First, the Color-Salient training condition, resembling the training of Choi et al. (2012), contains a red second target, and only short-lag trials. Second, the Lag-2 training condition contains no salient target, thus all stimuli are presented in black, and again, there are only short-lag trials (Choi et al., 2012). Third, the Lag-2&6 training is similar to the Lag-2 condition with the exception that the lags between the targets are variable, i.e., a short and a long lag. Based on the results of Choi et al., it is expected that the Color-Salient training will enhance performance at the short lag, such that the AB will be eliminated. Furthermore, if performance at the long lag is decreased after the Color-Salient training (Tang et al., 2013), this will reinforce the theory that temporal expectations underlie the training effect. Because the salient target is seen as a crucial factor in the training effect, no effects are expected in the Lag-2 condition and the Lag-2&6 condition.

Given that we do not expect an eliminated AB after both control conditions, the expectations with regard to training-induced changes in pupil dilation will focus on the Color-Salient condition. Here, we expect that if less cognitive effort is needed as a result of general enhanced processing post-training, this may be reflected in decreased amplitudes of the peaks that are associated with attentional target processing post-training compared to pre-training. In addition, if the training induces either an attentional strategy change (Choi et al., 2012) or strengthens temporal expectations (Tang et al., 2013), this could result in temporal changes in attentional allocation to the targets, as reflected in shifts of peak latencies. Finally, if training induces temporal expectations, we expect to observe increased expectation effects, i.e., increased attentional pulses associated with the expected, but not presented, second target, during single-target trials at the time points when a second target is expected to occur.

METHODS

A total of 81 students of the University of Groningen participated in the experiment in return for a €15 payment or course credits. All participants had normal or corrected-to-normal visual acuity, and no history of neurological problems. All participants performed a similar pre- and post-training task, but three different types of training were provided: the Color-Salient training (26 participants; 15 female; mean age = 21.7 (ranging 19-26)), the Lag-2 training (29 participants; 21 female; mean age = 21.4 (ranging 18-29)), and the Lag-2&6 training (26 participants; 16 female; mean age = 20.1 (ranging 18-25)). After preprocessing the eye data, four participants were excluded from the pupil dilation analyses due to too many artifacts. After exclusion, 25 participants remained in the Color-Salient condition, 27 in the Lag-2 condition, and 25 in the Lag-2&6 condition. The Psychology Ethical Committee of the University of Groningen approved the experimental protocol, and written informed consent was obtained

from each participant prior to the experiment.

BEHAVIORAL

AB task. The experiment was generated using E-prime 2.0 and presented on a 19-inch computer screen with a 100 Hz refresh rate. Participants performed an AB task in the practice block, the pre-training block, and the post-training block. The practice block contained 3 trials, and the pre- and post-training blocks contained 90 trials. In these blocks, each trial contained a Rapid Serial Visual Presentation (RSVP) of 32 items, which was presented in the middle of the screen at a rate of ~10 Hz with no inter-stimulus interval. Target stimuli consisted of uppercase consonants, excluding "Q", "V", and "Y", whereas distractor stimuli consisted of digits ranging 2-9. All stimuli were presented in black, 18-point Courier New on a white background. On a third of the trials, one target was presented, whereas on the remainder of the trials two targets were presented. The first target (T1) was always presented as the sixth stimulus of the RSVP. On dual-target trials, the second target (T2) was presented as either the eighth stimulus (lag 2) or the twelfth stimulus (lag 6). All types of trials (single-target, lag 2, and lag 6) were presented randomly and equally often. In addition, stimuli were selected pseudo-randomly, with the constraints that target letters were not repeated within a single trial and that distractor digits were not presented twice in succession. Preceding the stream, a fixation cross was presented for 850 ms. To ensure that participants would stay fixated on the middle of the screen until the end of the trial, a comma or a dot was shown for 100 ms following the last distractor. This comma or dot had to be identified in addition to the target letters and allowed for recording the pupil response to the second target. After each trial, participants were prompted to type in the letters on the keyboard in the order they had seen them or to press spacebar when no target was observed. Hereafter, participants had to indicate whether the last character was a comma or a dot.

Training task. The training block in each condition contained 450 trials. The trials were similar to the ones in the pre- and post-training block with the following exceptions. The RSVP consisted of 10 items and T1 was always presented as the second item of the stream. The Color-Salient training consisted of lag-2 trials only and T2 was always presented in red. The Lag-2 training also consisted of lag-2 trials only, however all stimuli were presented in black. In addition, the Lag-2&6 training contained both lag-2 and lag-6 trials, presented randomly and equally often. Here, all stimuli were also presented in black.

Participants could take a short break in between blocks and halfway through the training block. They completed the experiment in approximately 70 minutes.

Statistical methods. Statistical analyses were performed using the lmerTest package (Kuznetsova et al., 2013) in R (version 2.14.2, R Development Core team, 2012). The behavioral data were analyzed using Generalized Linear Mixed Models (GLMM), and Tukey's HSD tests were performed as post-hoc comparison tests. In all models, 'participants' was entered as random intercept, and fixed factors were included based on theoretical grounds. Trials in which T1 and T2 were identified correctly but reported in reversed order were also considered correct. Furthermore, tests for overdispersion

did not reveal any problems.

PUPIL DILATION

Pupil dilation was measured using the EyeLink 1000 eye tracker (www.sr-research.com). Prior to the experiment, the eye tracker camera was configured to track the left eye, and the eye tracker was then calibrated. Viewing distance was ~50 cm. Pupil dilation was measured during the pre- and post-training blocks. However, participants kept their head in a chin-rest during all blocks to keep task conditions comparable.

Pre-processing. The pupil data were sampled at 250 Hz and down-sampled to 50 Hz. The data of each trial were time-locked to the onset of T1. Segments containing eye blinks were recovered using linear interpolation or excluded based on semi-automatic inspection. The average pupil size during the 200 ms before stream onset was used as a baseline, and the data were normalized by applying the following formula:

$$\text{Xnorm} = \frac{\text{x-Baseline}}{\text{Baseline}}$$

Attentional pulses were estimated by using the pupil dilation deconvolution method (Wierda et al., 2012). Per combination of participant and condition, 80 pulses were modeled, starting 400 ms before stream onset. The set of pulse strengths i={w1, w2, w3, ..., w78, w79, w80} was convolved with the Erlang gamma function $h = s * t(n) * (t^{\frac{-n*t}{t_{max}}})$.

In this function, s is a scaling factor, n is the number of layers and t_{max} is the position of the maximum response. Following Wierda et al. (2012), these parameters were set to n = 10.1, t_{max} = 930 and s = 1/1027. The pulse strengths were obtained by optimizing the fit between the estimated signal $x = l * b + i * h$ and the measured pupil dilation signal, where l is the position of each pulse in vector i and b controls for linear drifts in the data. In contrast to Wierda et al., an inter-pulse interval of 50 ms was used in order to increase temporal resolution of the pulses. Furthermore, instead of the Nelder-Mead method we used the Levenberg-Marquardt algorithm (i.e., a non-linear least-squares algorithm) for optimizing the strengths of the attentional pulses. The advantage of the latter is that it is computationally cheap and converges towards the same unique solution every run, while the Nelder-Mead method yields slightly different outcomes due to randomization, such that it should be repeated multiple times to get a reliable solution.

Local peaks were calculated to determine the latency of the attentional pulses per target. Because there were substantial individual differences in the timing of the pulses, it was difficult to specify a general time window for all individuals that captured the T1 pulse, but did not include the T2 pulse. Therefore, based on the assumption that the first pulse following T1 presentation represents attentional allocation to this target, T1 latency was determined by selecting the first local peak within a time window of -100 to 500 ms. T2 latency was determined as the local peak within a window ranging 400 to 1000 ms for lag 2 and 800 to 1400 ms for lag 6. The amplitude of the pulses was calculated by averaging amplitudes of the local peak with that of the point preceding it and of the point following it.

Statistical methods. The latencies and amplitudes of the deconvolved attentional pulses were analyzed using Linear Mixed Models (LMM). Using the nlme package (Pinheiro et al., 2012), we fitted various covariance structures which were compared using the Akaike information criterion (Akaike, 1974). In all cases, either the initial model,

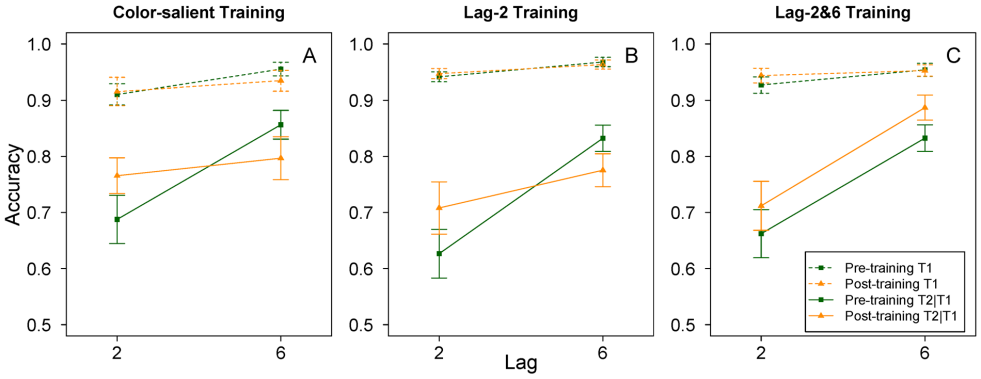

Figure 6.1. The mean percentage of correct reports of T1 (dotted lines) and T2 given correct report of T1 (solid lines) as a function of lag for the pre- (green squares) and the post-training block (orange triangles) in A) the color-salient condition, B) the lag-2 condition, and C) the lag-2&6 condition. The error bars reflect the standard errors of the mean.

which assumes that there are no within-group correlations, fitted best, or the results of the best fitting model did not differ from the initial model. We therefore used the initial model in all subsequent analyses. Expectancy effects in the single-target trials were analyzed by comparing the pulse strength in the pre- and post-training blocks within the same time windows as those that were used to determine T2-related pulses for lag-2 trials and lag-6 trials. A permutation test was performed per time point within these windows. Further statistical methods were similar to those for the behavioral data.

RESULTS

BEHAVIORAL

The mean accuracy for T1 and for T2 given correct report of T1 (T2 | T1) in the pre- and the post-training block in all three training conditions is shown in Figure 6.1. For T2 | T1 accuracy, we performed three behavioral omnibus GLMM with Lag (2 and 6), Session (pre-training session and post-training session), Condition (Color-Salient, Lag-2, and Lag-2&6), and its two-way and three-way interaction terms as fixed factors. For each model a different training condition served as reference category. A summary of the most important results of these models is presented in Table 6.1. The results of the full models can be found in Table 6.2A-C, included as supplementary information. We found that the Lag x Session interaction was different both in the Color-Salient condition compared to the Lag-2&6 condition, and in the Lag-2 condition compared to the Lag-2&6 condition. However, there was no evidence that the Lag x Session effect differed between the Color-Salient condition and the Lag-2 condition. As can be seen in Figure 6.1, there was a Lag x Session interaction in the Color-Salient condition and in the Lag-2 condition. However, this was not the case in the Lag-2&6 condition. For T1 accuracy, we performed a similar omnibus GLMM, and here we only found an unconditional main effect of Lag (β = -.47, *SE* = .09, z = -5.12, p < .001). There was neither an overall effect of Session (p = .96), nor any inter-

actions between the factors (p > .1).

Post-hoc tests revealed that after the Color-Salient training, T2|T1 accuracy improved at the short lag, but decreased at the long lag (ps < .004). Furthermore, T2|T1 accuracy was lower at lag 2 than at lag 6 pre-training (p < .001), but this difference was not found post-training (p = .061). After the Lag-2 training, there also was an increase in T2|T1 lag-2 performance and a decrease in lag-6 performance (ps < .003). Thus, accuracy changed in a similar fashion after the Lag-2 training as after the Color-Salient training. However, after the Lag-2 training, a difference in accuracy between lag 2 and lag 6 remained (p < .001). These results suggest that the AB was attenuated after both the Color-Salient training and the Lag-2 training, but not after the Lag-2&6 training (MacLean & Arnell, 2012). In the training block, mean T1 accuracy was 91.1% (SE = 1.6), 96.3% (SE = .6), and 95.0% (SE = .8) in the Color-Salient condition, the Lag-2 condition, and the Lag-2&6 condition, respectively. At lag 2, mean T2|T1 accuracy in the training block was 83.9% (SE = 3.1), 65.9% (SE = 3.9), and 64.7% (SE = 3.4) in the Color-Salient condition, the Lag-2 condition, and the Lag-2&6 condition, respectively. At lag 6 in the Lag-2&6 condition, mean T2|T1 accuracy was 90.4% (SE = 1.0) in the training block.

PUPIL DILATION

In order to study the attentional deployment during the pre- and post-training sessions, the normalized pupil dilation signal was deconvolved to attentional pulses that can be associated with the processing of the targets. For the T1 analyses concerning all lags, we only took trials into account in which T2 was correctly identified, i.e., no-blink trials. This was motivated by the lack or absence of blink trials, i.e., correct T1 and incorrect T2, during lag-6 trials and single-target trials. Differences between no-blink trials and blink trials were investigated for lag 2 in separate analyses. Furthermore, all LMMs were modeled with the constraint that T1 was reported correctly, and in the analyses concerning T2 pulses, only trials in which T2 was reported correctly were taken into account.

T1 latency. For T1 latency, i.e., the first local peak within the -100-500 ms time window, we analyzed whether Session (pre-training session and post-training session), Condition (Color-Salient, Lag-2, and Lag-2&6), and Session x Condition were predictive factors over all lags (single-target, lag 2, and lag 6). We found no evidence that the effect of Session differed between the Color-Salient training, the Lag-2 training, and the Lag-2&6 training (ps > .8). However, as depicted per lag and per condition in Figure 6.2-6.5, there was an unconditional main effect of Session (β = -56.04, SE = 12.11, t = -4.63, p < .001), which indicates that over all conditions attention was allocated earlier in time to the first target after the training compared to before the training. In addition, as tested in a separate LMM, T1 latency over all lags could not be predicted by individual mean T1 accuracy (p = .80).

For lag-2 trials only, we tested whether T2 accuracy (no-blink trials versus blink trials), Session, Condition, and their two-way interaction terms were predictive for T1 latency. These results are shown for blink trials and no-blink trials in Figure 6.2 and 6.3, respectively. There were no significant interactions (p > .1), but, again, there was an unconditional main effect of Ses-

Table 6.1. Summary of omnibus GLMM results with different reference categories

Factor	β	SE	z-value	p-value
Lag[1] x Session[2,3]	.86	.19	4.46	< .001*
Lag x Session x Lag-2 Condition[3]	-.05	.26	-.18	.856
Lag x Session[4]	.82	.17	4.71	< .001*
Lag x Session x Lag-2&6 Condition[4]	-1.05	.26	-3.99	< .001*
Lag x Session[5]	-.23	.20	-1.17	.241
Lag x Session x Color-Salient Condition[5]	1.10	.28	3.95	< .001*

Significance code: '*' < .001
[1] Reference category is "lag 6"
[2] Reference category is "pre-training session"
[3] Reference category is "Color-Salient condition"
[4] Reference category is "Lag-2 condition"
[5] Reference category is "Lag-2&6 condition"

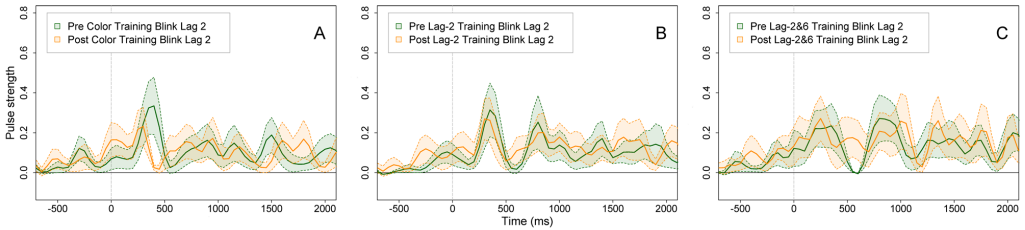

Figure 6.2. The mean strength of the deconvolved attentional pulses pre- and post-training for lag-2 blink trials, i.e., T1 reported correctly and T2 reported incorrectly, in the A) Color-Salient condition, B) Lag-2 condition, and C) Lag-2&6 condition. The x-axis is time-locked to the onset of T1 and the depicted signal was smoothed with a Butterworth filter. The error bars reflect the standard errors of the mean.

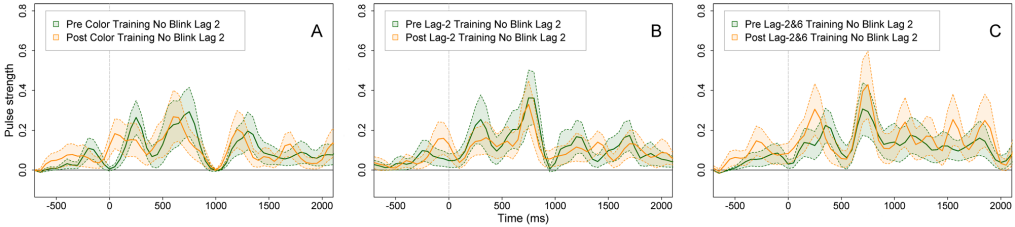

Figure 6.3. The mean strength of the deconvolved attentional pulses pre- and post-training for lag-2 no-blink trials, i.e., both targets reported correctly, in the A) Color-Salient condition, B) Lag-2 condition, and C) Lag-2&6 condition. The x-axis is time-locked to the onset of T1 and the depicted signal was smoothed with a Butterworth filter. The error bars reflect the standard errors of the mean.

sion (β = -60.06, *SE* = 16.59, *t* = -3.62, $p < .001$). This indicates that at lag-2 trials, T1 latency shifted to an earlier time point after the training in all conditions. The results did not indicate any differences between no-blink and blink trials (p = .25). Furthermore, neither AB magnitude (p = .35), defined as T2|T1 lag-2 accuracy normalized by T2|T1 lag-6 accuracy, nor mean T1 accuracy (p = .13) was predictive for T1 latency at lag-2 trials. Together, these results suggest that regardless of lag or condition, attention was earlier allocated to T1 in the post-training session compared to the pre-training session.

T1 amplitude. The amplitude of the T1 pulse over all lags was analyzed with an LMM with Session, Condition, and its interaction term as fixed factors. This model revealed that the Session effect of the Color-Salient training condition was different from the Session effect in the Lag-2&6 training condition (β = .09, *SE* = .04, *t* = 2.44, p = .015). That is, T1 amplitude increased significantly after the Lag-2&6 training (β = .07, *SE* = .03, *t* = 2.71, p = .007), but was not affected by the Color-Salient training (p = .46). However, T1 amplitude did not differ as a result of Session between the Color-Salient condition and the Lag-2 condition, or between the Lag-2 condition and the Lag-2&6 condition (ps > .09). Individual mean T1 ac-

curacy was not related to the strength of the T1 pulse (p = .95).

For lag-2 trials, as graphed in Figure 6.2 and 6.3, we performed an LMM on T1 amplitude with T2 accuracy, Session, Condition, and their two-way interactions as fixed factors. None of the factors interacted significantly with one another (p > .1), but overall, whether a trial was a blink trial or a no-blink trial was predictive for T1 amplitude (β = -.07, SE = .02, t = -3.18, p = .002): The strength of the T1 pulse was lower in trials where T2 was identified correctly than in trials where T2 was perceived incorrectly. Finally, we did not find an effect of AB magnitude (p = .28) or of mean T1 accuracy (p = .51) on T1 amplitude at lag 2. Taken together, these outcomes implicate that allocating less attention to the first target is related to correct identification of the second target.

T2 latency. For T2 lag-2 latency, we tested whether Session, Condition, and Session x Condition were predictive factors with regard to no-blink trials. These results are depicted per training condition in Figure 6.3. Except for an overall group difference between the Color-Salient condition and the Lag-2&6 condition (β = -73.97, SE = 30.11, t = -2.46, p = .016), which indicates possibly an initial group difference, no effects were found (p > .4). However, the timing of the T2 pulse was related to the mean T2|T1 accuracy at lag 2 (β = -122.42, SE = 54.19, t = -2.26, p = .026). Given that we only took trials into account where T2|T1 was identified correctly, this means that even for trials where performance is equal for all participants at trial level, there is a difference in the timing of attentional allocation that is related to individual mean T2|T1 performance. That is, an earlier T2 peak was related to better T2|T1 performance.

For T2 lag-6 latency, as shown in Figure 6.4, we performed similar LMMs as for T2 lag-2 latency. No effect of Session, Condition, or its interaction term was found (p > .1). However, again, the timing of the T2 pulse at lag 6 was related to T2|T1 performance at that particular lag (β = -144.34, SE = 67.48, t = -2.14, p = .034). Thus at lag 6, at trials where T2|T1 performance was correct, an earlier T2 peak was associated with higher T2|T1 accuracy. These results concerning T2 latency show that earlier allocation of attention to the second target was associated with higher individual T2|T1 accuracy.

T2 amplitude. With regard to T2 amplitude at lag-2 trials, there were no effects of Session, Condition, or Session x Condition (ps > .07). In addition, T2 lag-2 amplitude was not predicted by mean T2|T1 accuracy at that lag (p = .57). There were also no effects of Session, Condition, or Session x Condition for T2 lag-6 amplitude (ps > .3). However, T2|T1 accuracy at lag 6 was a marginally significant predictor of T2 lag-6 amplitude (β = .44, SE = .23, t = 1.95, p = .053), such that better performance was related to a higher amplitude.

Expectancy effects. In line with previous findings by Wierda et al. (2012), expectancy effects for a second target can be seen in the single target trials as shown per condition in Figure 6.5A-C. To determine whether these expectancy effects for T2 had increased after the training conditions, single-target trials were analyzed, but there was no evidence for enhanced expectancies of the second target after any of the training conditions (ps > .08). However, when inspecting Figure 6.5A-C visually, post-training enhanced activity around 1300 ms can be seen

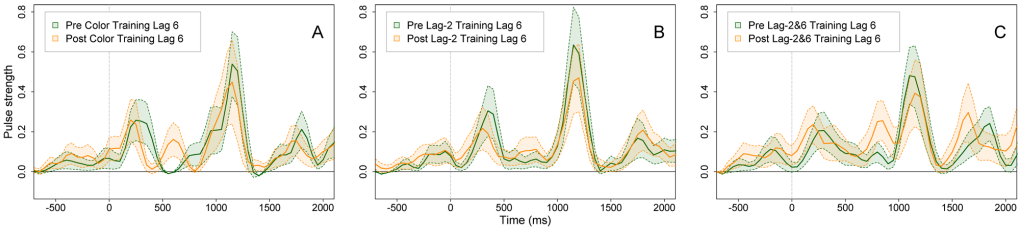

Figure 6.4. The mean strength of the deconvolved attentional pulses pre- and post-training for lag-6 no-blink trials, i.e., both targets reported correctly, in the A) Color-Salient condition, B) Lag-2 condition, and C) Lag-2&6 condition. The x-axis is time-locked to the onset of T1 and the depicted signal was smoothed with a Butterworth filter. The error bars reflect the standard errors of the mean.

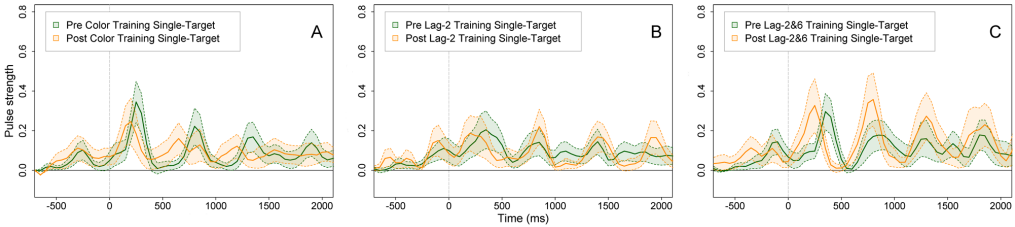

Figure 6.5. The mean strength of the deconvolved attentional pulses pre- and post-training for single-target no-blink trials, i.e., both targets reported correctly, in the A) Color-Salient condition, B) Lag-2 condition, and C) Lag-2&6 condition. The x-axis is time-locked to the onset of T1 and the depicted signal was smoothed with a Butterworth filter. The error bars reflect the standard errors of the mean.

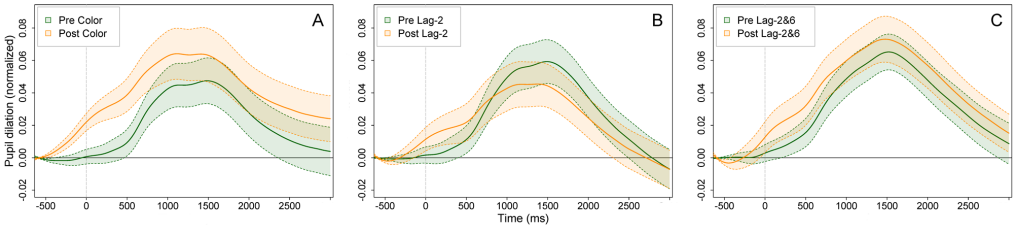

Figure 6.6. The averaged normalized pupil dilation for the pre- and the post-training block in A) the color-salient condition, B) the lag-2 condition, and C) the lag-2&6 condition. The x-axis is time-locked to the onset of T1 and the error bars reflect the standard errors of the mean.

in the Lag-2&6 condition compared to the Color-Salient condition and the Lag-2 condition. This point lies within the time frame we used to analyze T2 peaks at lag 6. In addition, after further visual inspection of the pupil data, we analyzed the time period 400-1000 ms in lag-6 trials, as shown in Figure 6.4A-C. This is the time window in which in case of lag-2 trials, the second target was presented. In the Color-Salient condition, the post-training activity was higher than the pre-training session at time point 500 (t = -2.14, p = .017). However, in the Lag-2 condition and the Lag-2&6 condition, there were no significant differences (p > .10).

Normalized pupil dilation. Finally, prompted after visual inspection of the data, we analyzed the normalized dilation data at the onset of the first target, at which target processing does not yet influence the dilation of the pupil. The results are graphed in Figure 6.6. We tested whether Session, Condition, and Session x Condition had an effect on the normalized size of the pupil. This model revealed that in every training condition, the normalized pupil dilation increased significantly as a result of Session (Color-Salient: β = .02, SE = .002, t = 14.44, p < .001; Lag-2: β = .001, SE = .002, t = 7.69, p < .001; Lag-2&6: β = .001, SE = .002, t = 7.42, p < .001). This increase was higher after the Color-Salient training than after both the Lag-2 training (β = -.01, SE = .002, t = -4.97, p < .001), and the Lag-2&6 training (β = -.01, SE = .002, t = -4.91, p < .001). The effect of Session did not differ between the Lag-2 and Lag-2&6 condition (p = .98). Furthermore, as tested in a model with AB magnitude, Condition, and AB magnitude x Condition as fixed factors, AB magnitude was a predictive factor for normalized pupil size in the Color-Salient condition (β = -.03, SE = .004, t = -8.97, p < .001) and in the Lag-2 condition (β = -.03, SE = .004, t = -7.08, p < .001), but not in the Lag-2&6 condition (p = .37). The difference between groups was also expressed in the interactions: The effect of AB magnitude differed between the Color-Salient condition and the Lag-2&6 condition (β = .04, SE = .01, t = 4.17, p < .001), and between the Lag-2 condition and the Lag-2&6 condition (β = .04, SE = .01, t = 3.56, p < .001). However, no evidence was found for a different effect of AB magnitude between the Color-Salient condition and the Lag-2 condition (p = .27). Thus, we found an increased pupil size in the post-training session, irrespective of training condition, and in the Color-Salient condition and the Lag-2 condition, this increase could be associated with the decrease of AB magnitude, but not in the Lag-2&6 condition.

DISCUSSION

In this study, we aimed to reveal training-induced changes in attentional allocation by measuring pupil dilation during a pre- and post-training AB task to elucidate the underlying mechanism of the color-salient training effect as found by Choi et al. (2012). On the one hand, it has been argued that the color-salient training may induce a fundamental improvement in target processing, which may be due to changes in top-down attention or to more efficient processing (Choi et al., 2012). On the other hand it has been suggested that this training may strengthen temporal expectations of the targets, which enhances target perception (Tang et al., 2013). In the current study, in addition to the Color-Salient training condition, we also included two control conditions: the Lag-2 training and the Lag-2&6 training.

In the behavioral data, we found that the AB was

eliminated after the Color-Salient training, thus replicating previous findings reported by Choi et al. (2012) and Tang et al. (2013). Surprisingly, however, we showed that training without a salient target, but with a consistent short target interval, is already sufficient to produce a similar effect. Only when the target interval in the training block was variable, no attenuation of the AB occurred after the training. The deconvolved pupil dilation data showed a shift in the timing of attention allocated to T1 rather than T2. However, this post-training shift was present in all three training conditions. Though expectancies for T2 were visible during single-target trials, they were not modulated by any type of training. In addition, whereas in all three conditions, the normalized post-training pupil dilation was enhanced prior to target onset compared to pre-training dilation, the increase was largest after the Color-Salient training. Finally, AB magnitude was found to be negatively related to the size of pre-target dilation in the Color-Salient condition and in the Lag-2 condition, but not in the Lag-2&6 condition.

TARGET EXPECTANCY

An important difference between the current behavioral findings and those by Choi et al. (2012) is that we found comparable reductions in AB magnitude in both the Color-Salient training and the Lag-2 training conditions. Choi et al. reported no such improvement in a similar control condition without color saliency (Exp. 3), and concluded that the salient T2 is crucial for the training effect. In addition, although compared between subjects, it was found that a constant time interval between the lags per block did not attenuate the AB compared to variable time intervals per block (Martens & Johnson, 2005). However, compared to Choi et al. and Martens and Johnson, in the current study, we tested a larger group of participants and analyzed the results more thoroughly by using mixed models instead of single t-tests, providing strong evidence that the presence of a salient target is not crucial to induce increased performance after training.

The behavioral results further suggest that temporal expectations play an important role in the improved accuracy. That is, in accordance with Tang et al. (2013), in both the Color-Salient condition and the Lag-2 condition, performance increased at lag 2, but decreased at lag 6. However, after the Lag-2&6 training, performance was enhanced equally at both lags. In other words, accuracy improved at the trained lags and decreased at the untrained lags, suggesting that training a specific time interval was likely to be an important aspect of the learning process.

This view seems to contradict the finding that the training effect was generalizable to multiple lags (Exp. 5, Choi et al., 2012). However, the results of Choi et al. actually show the largest improvement at lag 2 and 3, which are in close temporal proximity of each other, and resemble the trained interval. Furthermore, at first sight, it seems as if Choi and colleagues did not find the decrease in performance at the long lag, as was found by Tang et al. (2013) and observed in the current study. However, the slightly different presentation of the results by Choi et al. may play a crucial role here. In the Choi study, participants performed a pre-training task, the color-salient training, and a post-training task for three consecutive days. The results presented as post-training results in the Choi paper are actually the results from the pre-training

sessions on day two and three compared to the pre-training session on day one. In terms of the current experiment, this means that in the Choi study, the participants performed not only the Color-Salient training, but also a Lag-2&6 training prior to the block that was reported as post-training block. This can explain the combination of an eliminated attentional blink and the lack of decreased lag 6 performance. Furthermore, in line with our results, the supporting information of the Choi study shows that in the post-training block of the first day there was also a decrease in lag-6 T2|T1 performance. All of this taken together, our behavioral results indicate strongly that training strengthens temporal expectations, even without an explicit cue or a salient target.

PERFORMANCE-DRIVEN PUPIL CHANGES, INDEPENDENT OF TRAINING CONDITION

The pupil dilation data, however, are less straightforward than the behavioral data. We neither found any condition-related effects regarding the attentional allocation to the first and second target, nor any evidence for enhanced expectancies of the second target in the single-target trials. With regard to our hypotheses, we did not find any evidence for reduced peak amplitudes as a result of training, which indicates that the cognitive workload was not decreased post-training compared to pre-training. Therefore, it seems unlikely that general, more efficient target processing lies at the root of the training effect. However, overall, we did find decreased T1 amplitudes for no-blink trials compared to blink trials. This finding is in line with Wierda et al. (2012), and supports the theory that overinvestment of attention in T1 processing lies at the root of the AB effect (Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009; Wierda et al., 2010). Thus, the amount of invested attention in processing T1 seems important at trial-level, where it can predict whether the second target will be perceived correctly or not, but this was not influenced by any of the training conditions.

Irrespective of condition, post-training, we found a temporal shift of T1-allocated attention, and a higher level of normalized pupil dilation before any target processing. With regard to the normalized pupil dilation, we revealed that AB magnitude was negatively related to the size of the pupil at the onset of T1 processing in both the Color-Salient condition and the Lag-2 condition, but no such relationship was found in the Lag-2&6 condition. Ergo, after each training condition, normalized pupil size increased, and in the Color Salient condition and the Lag-2 condition this increase could be linked to AB magnitude, but not in the Lag-2&6 condition. Thus, although we found a link between post-training attention-based changes and performance differences, there was no indication that the Color-Salient training or the Lag-2 training, with similar behavioral results, induced different changes in pupil dilation than the Lag-2&6 training did. Because the behavioral patterns were not reflected in the pupil dilation associated with the targets in any of the training conditions, it seems unlikely that the attenuation of the AB is due to fundamental changes in attentional processing of the targets (Choi et al., 2012).

With regard to the temporal expectations theory (Tang et al., 2013), we did not find any training-induced differences in the expectation of the second target in the single-target trials. However, the earlier attentional allocation to T1 may be the result of enhanced temporal expectations of the

first target post-training. That is, a more precise attentional timing to T1 may result in less interference between the two targets at the short lag. In addition, the focus on the first target would also explain why the effect was generalizable to another task with a single target (Choi et al., 2012). Although a more precise attentional timing to T1 was not substantiated behaviorally by a training-induced increase in T1 performance, this may be explained by the fact that T1 performance was already at ceiling pre-training.

It remains unclear, however, why a more precise timing to T1 would result in decreased accuracy at a longer lag. A clue might be found in the lag-6 trials, which can be seen in Figure 6.2C, 6.3C, and 6.4C. Here, a post-training increase in activity can be seen in the period in which the short-lag T2 is expected, but not presented. However, this increase was only significant in the Color-Salient condition. A similar expectancy effect can be observed in single-target trials after the Lag-2&6 training. Here, in the timeframe 800-1400 ms, the level of activity seems strongest in the Lag-2&6 post-training condition (Figure 6.4D), when compared to the Color-Salient condition and the Lag-2 condition (Figure 6.2D and 6.3D). This might be an indication for increased temporal expectancies at the time point of the second target at lag 6 in the Lag-2&6 condition. However, within the Lag-2&6 condition, there was no significant increase in activity within this time period. Thus, inspection of the graphs does reveal some speculative clues that point towards strengthened temporal expectancies during the training tasks. However, clearly, future research is needed to establish the role of temporal expectations more thoroughly.

Finally, somewhat beyond the primary focus of our study, we observed a number of interesting relations between pupil dilation and performance on the AB task. First, the finding that the size of normalized pupil dilation before any target processing could be predicted by AB magnitude suggests a role of attentional preparation or strategy in individual AB task performance. Second, we found that the T1 amplitude was lower at trials where the second target was reported correctly than at trials where T2 identification failed. This strengthens the idea that the AB is due to an overinvestment of attention to T1 (Olivers & Nieuwenhuis, 2005, 2006; Shapiro et al., 2006; Taatgen et al., 2009; Wierda et al., 2010). Third, we found that overall the latency of T2-induced pupil dilation is related to individual mean T2|T1 accuracy at that particular lag, in spite of identical behavioral performance at trial level. Apparently, there are overall individual differences in the timing of attentional allocation that result in different levels of AB task performance, but which are not predictive at trial level. Future research is needed to further disentangle the relationship between individual differences in pupil dilation and individual differences in the AB.

In summary, the behavioral results suggest that the trained interval is an important part of the training effect, even without the presence of an explicit cue. The pupil dilation data showed a more complex picture. We found evidence for enhanced expectancies of the lag-2 second target in lag-6 trials after the Color-Salient training, but not for the seemingly enhanced expectancies in the other conditions. In addition, we found changes in attentional allocation to T1 and enhanced normalized pupil dilation after training.

Given that these changes generally occurred irrespective of the type of training, we concluded that the Color-Salient training does not induce a fundamental change in target processing (Choi et al., 2012). It seems plausible, though, that the shift in timing of allocated attention to T1 was due to enhanced temporal preparation for the first target, which is in line with the temporal expectation theory (Tang et al., 2013).

CONCLUSION

In the current study, we have demonstrated that a training task without a salient target, but with a consistent inter-target interval, can reduce the AB. Furthermore, our results point to the existence of temporal expectations at the time points of the trained targets post-training. At least a major source of the training effect as originally reported by Choi et al. must therefore lie in the strengthening of temporal expectations.

Charlotte Willems and Sander Martens

TRAINING THE BRAIN: A NON-RSVP TASK ATTENUATES THE ATTENTIONAL BLINK

ABSTRACT

The attentional blink (AB) is the frequent failure to identify a second target (T2) when it is presented in close temporal proximity of a first target (T1). Despite the assumption that the AB is robust, studies have shown that AB task performance can be enhanced or even resolved by training. The effect of one of these training tasks, containing a color-salient T2, was found to transfer to a target-mask task, where a single, masked target had to be identified. To further investigate these training effects, in the current study, we trained participants with a target-mask task to improve AB task performance. We measured pupil dilation to reveal any training-induced changes in attentional allocation.

We found that AB magnitude can be attenuated by the target-mask training, where the presentation time of target and mask were dynamically adapted to individual accuracy levels. This training effect carried over to a second post-training AB session about one month later. We found no differences in patterns of attentional allocation when comparing pre- and post-training pupil dilation, but there was evidence for reduced and earlier attentional allocation to the first target in the second post-training session compared to the first session.

We conclude that AB task performance can be improved robustly by a non-RSVP task, in which difficulty of discriminating between task-relevant and task-irrelevant information was tailored to individual performance. Rather than a simple increase in processing speed alone, we expect that this target-mask training effect is due to enhanced attentional selectivity that results in a more efficient differentiation between relevant information and irrelevant information.

INTRODUCTION

Distinguishing between relevant and irrelevant information is crucial for daily functioning in this ever-changing world. However, we are not always able to control this selection of information as much as we might want to; there are situations in which most people frequently fail to attend to relevant information, despite all effort. Within the lab, an example of such a cognitive limitation is the attentional blink (AB; Raymond et al., 1992). In this paradigm, two targets that have to be identified are presented in a rapid stream of distractor stimuli. If the second target (T2) is presented in close temporal succession of the first target (T1), identification of T2 often fails. Systematically varying the temporal interval between the targets allows researchers to study the dynamics of temporal selective attention. However, the precise mechanism underlying the AB is still under debate (for reviews see: Dux & Marois, 2009; Martens & Wyble, 2010).

Recently, it has been found that it is possible to resolve the AB by training individuals with a short rapid serial visual presentation (RSVP) task in which T2 is presented in a salient color and at a fixed short interval from T1 (Choi et al., 2012). Although, it has been shown that AB task performance can be enhanced by training participants with action video gaming (Green & Bavelier, 2003; Oei & Patterson, 2013) or practicing meditation (Slagter et al., 2007, 2009), the training effect of the color-salient training was surprising given that in the previous twenty years it had been assumed that the AB could not be resolved (Braun, 1998; Taatgen et al., 2009). Choi et al. found that the color-salient training was generalizable both over time and to another task, namely a single target-mask task. In this task a single target was presented and masked by a distractor stimulus, and accuracy on this task improved after the color-salient training task. Earlier, using a target-mask task where two masked target stimuli were presented at a variable lag, individual AB task performance had already been found to correlate with performance in the target-mask task (McLaughlin et al., 2001). Therefore, it seems plausible that the AB task and the target-mask task share a common factor reflected in related performances in these tasks.

As was suggested by Tang et al. (2013), the color-salient training may be the result of learning the specific timing of the targets. Because the targets in the training are presented at a fixed short interval, it may be the case that temporal expectations are created during the training regarding this short time interval (also see: Martens & Johnson, 2005). This hypothesis was confirmed by multiple findings: First, the training effect could be reduced by increasing the variability of target positions in either the pre- and post-training task or in the training session itself (Tang et al., 2013). Second, we found that a training without a color-salient target but with a fixed interval between the targets was sufficient to enhance AB task performance (Willems et al., 2015). Finally, it was revealed that performance at the long lag decreased after training on the fixed short lag irrespective of the presence of a salient target (Tang et al., 2013; Willems et al., 2015). Based on these findings, it seems that the color-salient training effect is at least partially determined by the build-up of temporal expectancies of the targets. However, it remains unclear why the color-salient training effect was found to be transferable to the non-RSVP target-mask task (Choi et al., 2012), as this cannot be explained by temporal expectancy.

In order to further study training effects on the AB, here we will test whether the AB can also be resolved by training individuals with a target-mask task. Given the findings that individual AB task performance was related to target-mask task performance (McLaughlin et al., 2001), and that color-salient training improved target-mask task accuracy (Choi et al., 2012), we hypothesize that training with the target-mask task will increase AB task performance. We further hypothesize that the target-mask training specifically improves the speed and efficiency of distinguishing relevant information, i.e., the target, from irrelevant information, i.e., the mask, rather than a general improvement in the speed of responding to the targets. To test this, a speeded-response training with an unmasked target was included as a control condition.

Assuming that we will find an effect of the target-mask training, but not of the speeded-response training, a subsequent goal is to test the robustness of the target-mask training effect by re-testing participants on the AB task about one month after the first session. We expected the training effect to persist over time given that the color-salient training effect was found to last over time as well (Choi et al., 2012). Finally, to test for differences between pre- and post-training patterns of attentional allocation, we measured pupil dilation, which is assumed to reflect attentional effort (Hoeks & Levelt, 1993; Kahneman & Beatty, 1966). Here, because the initial pupillary response is slow and peaks only after about one second following a relevant event, we used the pupil dilation deconvolution method to isolate target-related activity (Wierda et al., 2012; Willems et al., 2015).

METHODS

The experiment consisted of a target-mask experimental condition and a speeded-response control condition. In both conditions, the task contained a practice, pre-training, training, and post-training block. Per condition, the pre- and post-training blocks were identical, but the training session differed. Two groups of participants performed either a target-mask training, or a speeded-response training. Furthermore, to test the robustness of the target-mask training, participants in the target-mask training group were re-tested on the AB task in a second session 28-32 days after the first session. During all blocks containing the AB task (pre-training, post-training in the first session, and post-training in the second session), we measured pupil dilation.

PARTICIPANTS

A total of 63 participants were recruited at the University of Groningen (40 women, age ranging 18-27, mean = 20,3, *SD* = 2,2). Thirty-three participants performed the target-mask training task, and 30 participants the speeded-response training task. They participated in exchange for either course credits or €10 payment, and all had normal or corrected-to-normal vision. One person was excluded due to low T1 accuracy (<50%), which left 29 participants in the speeded-response condition. The protocol was approved by the Psychology Ethical Committee of the University of Groningen, and all participants signed written informed consent before the start of the experiment.

APPARATUS AND STIMULI

The experiment was generated with E-prime 2.0, and presented on a 19-inch monitor with a 100-Hz refresh rate. Target stimuli consisted of uppercase consonants excluding Q, V, and Y, and distractor stimuli consisted of digits ranging 2-9. The stimuli were presented in black, 18-point Courier New on a white background. Pupil dilation was measured using the Eye-Link 1000 (www.sr-research.com), and participants kept their head in a chin-rest during the experiment. Viewing distance was ~50 cm.

PROCEDURE

AB task. Each session started with a practice block of 20 trials. The pre-training, post-training, and second-session post-training AB task contained 170 trials each. Each RSVP of 32 stimuli was preceded by a fixation cross of 1000 ms and presented at a rate of 10 Hz. The RSVPs contained two, one, or no targets referred to as dual-target (102 trials), single-target (34 trials), and no-target trials (34 trials), respectively. In dual-target and single-target trials, T1 was always presented as the 4th stimulus in the stream. In case

of dual-target trials, T2 was presented as the 1st, 3rd or 8th item following T1, i.e., lag 1, 3, and 8 (34 trials each), respectively. Stimuli were presented pseudo-randomly with the constraint that a digit distractor was never similar to a preceding digit, and that a letter target was never repeated in one trial.

Target-mask training. In the target-mask training, participants performed 4 blocks of 125 trials, preceded by a practice block of 20 trials. Each trial started with a fixation cross of 600, 800, 1000, or 1200 ms, chosen randomly. Subsequently, a letter was presented that was masked by a digit. Together, the letter target and the distractor digit were always presented for 105 ms, but the length of the target and mask were dynamically adapted to individual performance levels throughout the training with a starting point of 40 ms for the target duration. If the running average of target accuracy was <75% or >85% for more than 4 trials in a row, the target duration was shortened or extended with 10 ms, respectively.

In between trials, participants received feedback about their performance. For each correct answer they gained 5 points, whereas for each incorrect answer they lost 5 points. The feedback screen included both feedback per trial and the total score. Before the training started, participants were told that they would win a candy bar if their final score reached at least 1400 points.

Speeded-response training. All aspects of the speeded-response training were similar to the target-mask training, with the exception that the target letter was not masked, and that participants were instructed to press the corresponding letter key as fast as possible on the keyboard. The letter remained present on the screen until the participant pressed a key. The feedback system was also similar to the target-mask training, but here, participants could gain another 5 more points (max of 10 per trial) if their response was faster than their mean reaction time. Here, the threshold to win a candy bar was 3700 points.

PUPIL DILATION

Pupil data were pre-processed and deconvolved as in (Willems et al., 2015), using automatic dilation deconvolution based on the quantitative analysis of the pupillary response (Hoeks & Levelt, 1993). The resulting pattern of attentional pulses allowed us to isolate and track the dynamics of attention, uncovering the amount of mental activity that was critical for conscious perception of the targets (Wierda et al., 2012; Willems et al., 2015). Latency of the peaks associated with T1 was defined as the first local peak within a time window of -100 to 500 ms relative to the onset of T1, whereas latency for T2 was defined as the local peak within a time window of 500 to 1100 ms for lag 3, and 1000 to 1600 ms for lag 8, relative to the onset of T1. The amplitude of the peak was calculated by averaging the strength of the peak and both the data point preceding and following the peak.

STATISTICAL METHODS

Statistical analyses were performed using R (version 2.14.2, R Development Core team, 2012). We analyzed behavioral data using generalized linear mixed models (GLMM), and pupil data were analyzed with linear mixed models (LMM) (lmerTest package; Kuznetsova et al., 2013). All mixed models contained "participants" as random intercept, and in case of any overdispersion, an observation-level random in-

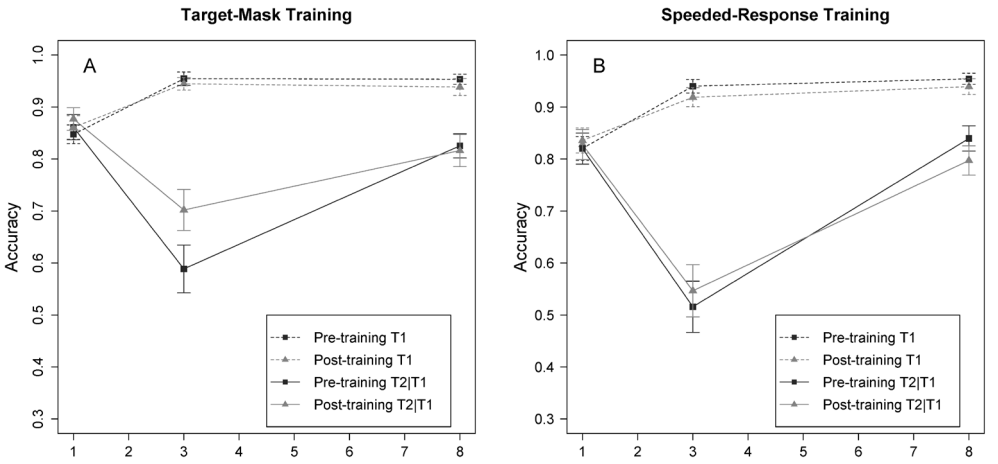

Figure 7.1. Behavioral performance for T1 and T2 given correct report of T1 (T2|T1) in the pre- and post-training AB task session in the A) target-mask training condition, and B) speeded-response training condition. Error bars reflect standard errors.

tercept was added to the model. Interaction terms of fixed factors are included based on ANOVA comparisons of models.

RESULTS

BEHAVIORAL

Target-mask training: Session 1. In Figure 7.1A, T1 accuracy and T2 accuracy given correct report of T1 (T2|T1) are depicted in the pre- and post-training session in the target-mask condition. For T1, a GLMM with Lag and Training as fixed factors showed no effect of Training ($p > .54$), and T1 accuracy differed between lag 1 and 3, $\beta = 1.27$, $SE = .12$, $z = 10.72$, $p < .001$; and between lag 1 and 8, $\beta = 1.19$, $SE = .12$, $z = 10.30$, $p < .001$; but not between lag 3 and 8 ($p > .58$). T1 accuracy in the single-target trials was 93.7% ($SE = .7$) pre-training and 96.1% ($SE = .6$) post-training.

For T2|T1, with a GLMM with Lag, Training, and Lag x Training as fixed factors and "Lag 1", and "Pre-Training" as reference levels, we found a Lag 3 x Post-Training effect, $\beta = .44$, $SE = .18$, $z = 2.49$, $p = .013$; but no Lag 8 x Post-Training effect ($p > .29$). Furthermore, when changing the lag reference level to "Lag 8" to compare T2|T1 accuracy between lag 3 and lag 8, we found a Lag 3 x Post-Training effect, $\beta = .63$, $SE = .15$, $z = 4.10$, $p < .001$. As shown in Figure 7.1A, these interaction effects indicate that whereas performance at lag 1 and 8 stayed comparable between pre- and post-training sessions, performance at lag 3 increased after training. However, after the target-mask training, there was still an AB present, as was confirmed by Tukey's HSD post-hoc comparisons of post-training lag 1 and lag 3 T2|T1 accuracy ($p < .001$), and post-training lag 8 and lag 3 T2|T1 accuracy ($p < .001$).

Speeded-response training. In Figure 7.1B, we graphed T1 accuracy and T2|T1 accuracy in the pre- and post-training session in the speeded-response

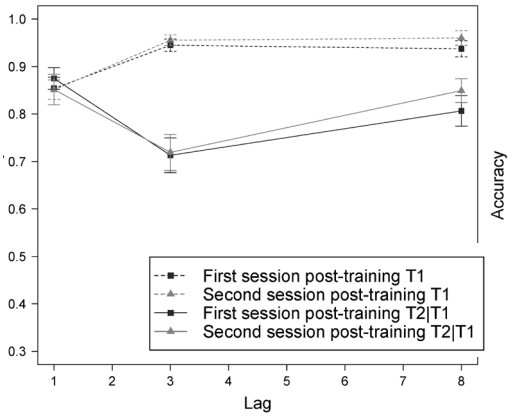

Figure 7.2. Behavioral performance for T1 and T2|T1 in the first and second post-training AB task session. Error bars reflect standard errors.

control condition. A GLMM for T1 with Lag and Training as fixed factors revealed no effect of Training (p > .33), but T1 accuracy differed between lag 1 and 3, β = 1.08, SE = .11, z = 9.84, p < .001; lag 1 and 8, β = 1.39, SE = .12, z = 11.59, p < .001; and lag 3 and 8, β = .31, SE = .14, z = 2.29, p = .022. In the single-target trials, T1 accuracy was 94.2% (SE = .5) and 94.6% (SE = .5) pre-and post-training, respectively.

For T2|T1 accuracy, we tested Lag, Training, and Lag x Training as fixed factors in a GLMM. With "Lag 1" and "Pre-Training" as reference levels, we found no Lag 3 x Post-Training effect (p > .66), but there was a Lag 8 x Post-Training effect, β = -.39, SE = .19, z = -2.06, p = .040. Switching to "Lag 8" as reference level, we found a Lag 3 x Post-Training effect, β = .47, SE = .16, z = 2.86, p = .004. As can also be seen in Figure 7.1B, the latter two interaction effects indicate that T2|T1 accuracy at lag 8 is lower post-training than pre-training, whereas T2|T1 accuracy at lag 1 and 3 does not differ between pre- and post-training sessions.

Target-mask training: Session 2. Out of 33 participants, 2 participants did not perform the second AB task session, which left 31 participants for the following analysis. Post-training accuracy in both the first session and the second session are shown in Figure 7.2. To compare T1 accuracy in the post-training block in the first session with the post-training block in the second session, we performed a GLMM with Lag and Session (1 vs 2) as fixed factors. There was a main effect of lag when comparing lag 1 with lag 8, β = 1.26, SE = .12, z = 10.45, p < .001; lag 1 with lag 3, β = 1.30, SE = .12, z = 10.61, p < .001; but not when comparing lag 8 with lag 3 (p > .83). Furthermore, there was no effect of Session (p > .12) on T1 accuracy.

For T2|T1 accuracy, we performed a comparable GLMM, but with Lag x Session added to the model. With "Lag 1" and "Session 1" as reference levels, we found a Lag 8 x Session 2 effect, β = .55, SE = .19, z = 2.83, p = .005; and no significant Lag 3 x Session 2 effect (p = .19). When changing the lag reference level to "Lag 8", we

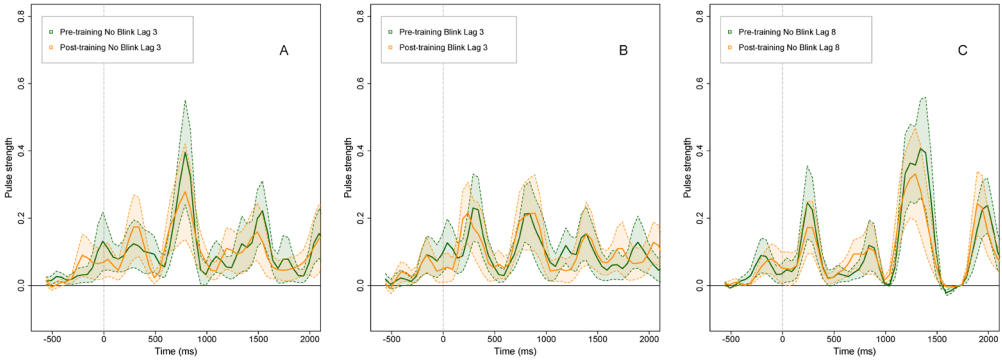

Figure 7.3. The deconvolved pupil signal in the target-mask training session as measured in the pre- and post-training blocks for A) lag-3 no-blink trials, B) lag-3 blink trials, and C) lag-8 no-blink trials. The depicted signal is smoothed with a Butterworth filter, and error bars reflect standard errors.

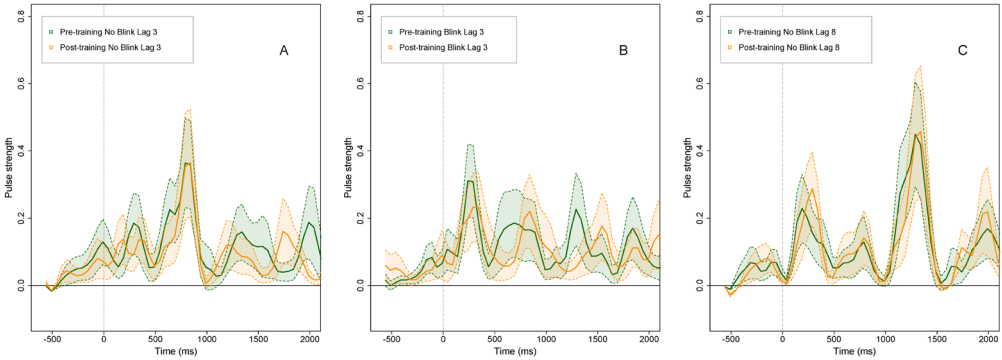

Figure 7.4. The deconvolved pupil signal in the speeded-response control training session as measured in the pre- and post-training blocks for A) lag-3 no-blink trials, B) lag-3 blink trials, and C) lag-8 no-blink trials. The depicted signal is smoothed with a Butterworth filter, and error bars reflect standard errors.

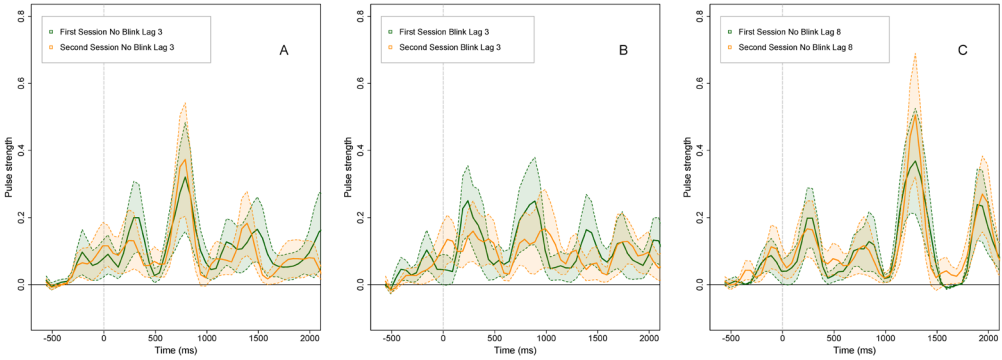

Figure 7.5. The deconvolved pupil signal in the target-mask training session as measured in the first and second post-target-mask training blocks for A) lag-3 no-blink trials, B) lag-3 blink trials, and C) lag-8 no-blink trials. The depicted signal is smoothed with a Butterworth filter, and error bars reflect standard errors.

found a borderline significant Lag 3 x Session 2 effect, β = -.31, *SE* = .16, *z* = -1.91, *p* = .056. As depicted in Figure 7.2, these results indicate that after one month performance at lag 1 decreased a little, whereas performance at lag 8 increased. However, Tukey's HSD post-hoc comparisons revealed no accuracy differences between the first and second session for both lag 1 ($p > .75$) and lag 8 ($p > .06$). Most importantly, post-training performance at lag 3 remained comparable between the first and second session ($p > .99$), which suggests that the beneficial training effect persisted for at least a month.

PUPIL DILATION

Regarding the following pupil dilation data analyses, two participants in the target-mask training condition and one participant in the speeded-response training condition were excluded due to too many artifacts in the data, thus leaving 31 participants in the target-mask condition, and 28 in the speeded-response condition. For the analyses comparing pupil data in the first and second post-target-mask training sessions, another two participants were excluded due to too many artifacts, which left 27 participants for these comparisons.

Target-mask training: Session 1. For both T1 and T2|T1, we found no changes in timing or investment of attention when comparing pre- and post-training pulses. This was the case for both lag-3 ($ps > .25$) and lag-8 trials ($ps > .69$), as graphed in Figure 7.3A-C. Lag-3 specific analyses also showed no difference in latency or amplitude between trials where T1 was identified, but T2 was missed, i.e., blink trials, and trials where both targets were correctly identified, i.e., no-blink trials ($ps > .13$).

Speeded-response training. As shown in Figure 7.4A-C, for both lag 3 ($p > .16$) and lag 8 ($p > .62$), we found no training-induced changes in latency or amplitude of the attentional pulses related to T1 and T2|T1. Regarding the amount of attention on lag-3 trials, we found a difference in T1 amplitude between blink trials and no-blink trials, β = -.21, *SE* = .10, *t* = -2.14, *p* = .036, indicating that participants invested less attention to T1 in no-blink trials. There was no difference in latency between lag-3 blink and no-blink trials ($p > .95$).

Target-mask training: Session 2. When comparing T1 pulses in lag-3 trials of the first post-training session with those of the second post-training session, we found significant differences in both latency, β = -65.07, *SE* = 28.79, *t* = -2.26, *p* = .027; and amplitude, β = -.33, *SE* = .10, *t* = -3.43, *p* = .001. These results show that for lag-3 trials in the second post-training session, individuals were earlier in allocating attention to T1, and invested less attention in T1 compared to the first post-training session. This is also depicted in Figure 7.5A-B. Further comparing timing and investment of attention to T1, there was neither an effect of blink/no-blink trials for lag-3 trials ($p > .35$), nor of session for no-blink lag-8 trials ($p > .34$). For T2|T1, there were no effects of session on latency or amplitude at lag 3 ($ps > .73$) or lag 8 ($ps > .40$).

DISCUSSION

In the current study we aimed to investigate training effects in the AB paradigm, by testing whether performance in the AB task could be enhanced by a training session consisting of a single target-mask task. Furthermore, we wanted to test the robustness of any target-mask

training effects by re-testing participants on the AB task about one month after they received the training. To reveal any training-induced changes in attentional allocation, we measured pupil dilation and used the pupil dilation deconvolution method (Wierda et al., 2012) to track target-specific changes in patterns of attention between the pre- and post-training AB sessions. Based on earlier findings (Choi et al., 2012; McLaughlin et al., 2001), we expected that the target-mask training would diminish the AB, and that this effect would carry over to the second AB session about one month later.

As expected, we found that the target-mask training attenuated the AB, as was indicated by the increased post-training T2|T1 accuracy at lag 3. The training did not completely resolve the AB, though, because there remained a dip in T2|T1 accuracy at lag 3 post-training. Furthermore, we found similar levels of T2|T1 accuracy in the second AB post-training session compared to the first AB post-training session, showing that the beneficial effect of the target-mask training lasted for at least one month. As expected, there was no effect of the speeded-response training on AB task performance. In the pupil dilation data, there was no evidence for any training-induced changes in attentional allocation comparing pre- and post-training sessions in both the target-mask condition and the speeded-response condition. Regarding the first and second session following the target-mask training, we found that participants in the second AB session allocated less attention to T1 and did this earlier in time than in the first post-training session. Furthermore, we found a significant difference in attentional investment between blink and no-blink trials for T1 in the speeded-response training condition, but not in the target-mask training condition.

The finding that the target-mask training enhanced performance in the post-training AB task is in line with the earlier finding of Choi et al. (2012) that the color-salient training enhanced performance both in the AB task and in the target-mask task. Moreover, the color-salient training effect also lasted over a longer period of time, as was the case for the target-mask training in the current study. Furthermore, the current results confirm the relation between individual performance in a target-mask task and the AB task (McLaughlin et al., 2001). Thus, it seems that performance in both these tasks is related, and that performance in the AB task can be trained with the target-mask task.

The findings of this study are harder to interpret in the context of the temporal expectations hypothesis that assumes the color-salient training effect to be the result of learning the timing of the targets. Earlier findings have suggested that the color-salient training effect is due to temporal expectations (Tang et al., 2013; Willems et al., 2015). However, here, we show that the AB can also be diminished by a non-RSVP training paradigm that did not provide information regarding the timing of stimuli within the AB task. In addition to the finding that the color-salient training effect was transferable to the target-mask task (Choi et al., 2012), it thus seems that the color-salient training effect relies on more factors than just learning the timing of the targets.

The question remains, though, how the non-RSVP target-mask task can improve performance in the AB task. One explanation may be that the target-mask task trains individuals to distinguish relevant information from irrelevant information faster and/or more efficiently. Because the mask was dynamically adapted to individual performance levels, individuals were constantly challenged to discriminate between the target and the mask. Given that we found no training effect after the speeded-response training, where the instruction was to identify the target as fast as possible, it can be assumed that focusing on speed of processing alone could not enhance performance in the AB task. This is also in line with findings that speed of processing cannot be linked to individual AB task performance; whereas the level of target accuracy can be predicted by how fast individuals process information, as tested with the rapid automatized naming task, speed of processing has not been found to be predictive for AB magnitude (Martens, Munneke, et al., 2006; McLean et al., 2009; Visser & Ohan, 2012). If the target-mask training increases efficiency and/or speed of attentional selection, this would be in line with the findings that individuals with a small AB show earlier (Willems et al., 2015) and more precise (Willems et al., 2013) allocation of attention. Moreover, a small AB magnitude has been related to earlier updating of working memory (Martens, Munneke, et al., 2006). Furthermore, the importance of tailoring a training task to individual differences is confirmed by Reedijk et al. (2015), where it was found that the effect of training differed between individuals depending on striatal dopamine levels. Following this, we assume that identifying the rapidly masked target does not simply induce a general increase in processing speed, but causes individuals to be more efficient and/or faster in discriminating relevant from irrelevant information in the process of temporal selective attention.

Regarding the pupil dilation data, we found no changes in attentional allocation after the training. The absence of this training effect can be explained in multiple ways. First, with hindsight, methodological limitations might have interfered with our attempts to reveal training-induced changes in pupil dilation, because in the current paradigm we used fewer trials than in the original pupil dilation study (Wierda et al., 2012) that used 60 rather than 30 trials per condition. Therefore, we cannot exclude that the number of trials per condition in the current study was insufficient to detect any training-induced effects.

One alternative possibility, though, is that the methods were sufficient for pupil dilation measurements, but that the pattern of attention/mental effort on blink versus no-blink trials did not change. Given that earlier we also found no clear training effects using pupil dilation (Willems et al., 2015), it is possible that the training just changed the ratio of blink/no-blink trials, i.e., fewer blink trials post- training than pre-training, but not the attentional dynamics associated with these specific types of trials. In that case, the pattern of pupil dilation on blink and no-blink trials would not be different either preceding or following the training.

We did find a difference in timing and investment of attention when comparing pupil dilation between the first and second post-training session in the target mask condition. Given that we found no changes in behavior between these two sessions, this difference in pupil dilation may

perhaps be explained by a lower level of fatigue or increased habituation regarding the task in the second post-training AB session. Another speculative explanation may be that in between the two sessions, the AB task, the training task, or both became better consolidated in memory during periods of sleep. Because it has been found that sleep causes initial memory representations to become more permanent (Walker & Stickgold, 2004), the changes in attentional allocation in the second AB session might reflect such stabilized representations. However, because the current experiment did not contain a second testing session for the speeded-response condition, unfortunately, we could not compare the target-mask training condition with a control condition in the second session. Therefore, further studies will have to examine the possible influence of fatigue, habituation, and sleep over time on pupil dilation to clarify the current result.

In summary, we showed that AB magnitude can be attenuated by a target-mask training, where the presentation time of target and mask were dynamically adapted to individual accuracy levels. Furthermore, we showed that this training effect carried over to a second post-training AB session about one month later. We found no differences in patterns of attentional allocation when comparing pre- and post-training pupil dilation, but there was evidence for reduced and earlier attentional allocation to the first target in the second post-training session compared to the first session.

We conclude that AB task performance can be improved robustly by a non-RSVP task, in which the difficulty of discriminating between task-relevant and task-irrelevant information is tailored to individual performance levels. Furthermore, this training task lacks the possibility to create temporal expectancies regarding the target positions in the RSVP. Rather than a simple increase in processing speed alone, we expect that this target-mask training effect is due to enhanced attentional selectivity that results in a more efficient differentiation between relevant information and irrelevant information.

SUMMARY AND GENERAL DISCUSSION

INDIVIDUAL DIFFERENCES

In the first part of this thesis, I focused on identifying the underlying cause of the existence of inter-individual differences in AB task performance. To summarize, in the 2nd chapter, I presented a review of the literature regarding individual differences in AB task performance to examine its contribution to a better understanding of the AB phenomenon. First, we established that individual differences in the AB are reliable within tasks, across tasks, and over time, which confirms that the individual differences approach is a valid way to study the nature of the AB. Second, we showed that individuals with higher levels of executive WM functioning and broad attentional focus tend to perform better in the AB paradigm than individuals with lower levels of executive WM functioning and narrow attentional focus. Thus, individual differences studies indicate that the AB is a multifaceted phenomenon that, inter alia, arises from operational WM functioning and the span of attentional focus.

Subsequently, in chapter 3, it was shown that the analysis of error patterns in relation to individual AB task performance reveals information about the temporal dynamics of attentional selection. Focusing on three dimensions of temporal selective attention, i.e., suppression, delay, and diffusion, we found only modest signs of suppression of both targets and target-surrounding distractor letters for large blinkers, and no signs of suppression at all for small blinkers. The latter finding was unexpected, because earlier studies have suggested that individual differences in the AB may be due to differences in the applied strength of suppression of distractor stimuli (Dux & Marois, 2008; Slagter & Georgopoulou, 2013). In addition, these results do not support the assumption that the AB is due to suppression of T2 (Olivers & Meeter, 2008; Wyble et al., 2009). An explanation for our findings may be that using an RSVP containing only letter stimuli - with targets appearing in red among black distractor - has influenced the role of suppression in relation to individual AB task performance; suppression might be only relevant when targets and distractors can be more easily discriminated, e.g., in a paradigm using alphanumerical stimuli. Furthermore, we showed that individuals differed in latency of target selection, which was defined as the center of mass of individual target report. Small blinkers showed most delay of temporal selective attention at lag 1, after which delay decreased as a function of time, whereas large blinkers showed least delay at lag 1, after which delay increased as a function of time. Although our results were different from other studies investigating delay of attentional selection (Chun, 1997; Vul, Nieuwenstein, et al., 2008), this may be accounted for by the individual differences approach; patterns of delayed attentional

selection might depend on individual AB magnitude (Bourassa et al., 2015). Moreover, small blinkers were found to be more precise in their selection process, as reflected in less variability in their target reports. In addition, relative to task performance, large blinkers made fewer intrusion errors, i.e., reported less often a neighboring distractor as being the target, in case of an error. Finally, if both targets were identified correctly, small blinkers reported the targets less often in reversed order than large blinkers did. Thus, composing the temporal profile of individual AB magnitude, it seems that a smaller AB magnitude is related both to a more precise timing of temporal selective attention and to higher availability of target-surrounding information. Furthermore, in contrast to the theory that the AB is due to preserving episodic distinctiveness (Wyble et al., 2009), the lower number of order reversals for small blinkers suggests that a small AB is related to higher preservation of temporal order information.

In chapter 4, we elaborated on the results of the previous chapter by investigating the tendency to integrate two visual events into one temporal event in relation to individual AB task performance. Based on the suggestion that order reversals in paradigms using alphanumeric stimuli may actually reflect temporal integration (Akyürek et al., 2012), we expected individuals with a small AB to use a smaller temporal window in which information is integrated, i.e., to show less temporal integration, than individuals with a large AB. Using a paradigm with symbol target stimuli that allowed meaningful integration into a single concept, we indeed found that a smaller AB magnitude was related to less integration of both targets. This finding is not in line with the idea that the AB is due to preservation of episodic distinctiveness, (Wyble et al., 2009), because in that case, the exact opposite pattern would be expected. Moreover, in contrast to the results in chapter 3, we found no relation between individual AB magnitude and the number of order reversals. Though, the current order reversals may be considered to be 'true' order reversals given that temporal integration was possible, while the relation as found in chapter 3 may be accounted for by order reversals that actually reflect temporal integration of targets. Thus, these results indicate that better AB task performance is related to the use of a smaller temporal window that results in higher preservation of temporal information. Furthermore, as already hypothesized by Akyürek et al. (2012), order reversals in classic AB paradigms using alphanumeric stimuli seem to at least partly reflect temporal integration of the targets into one perceptual event.

In the final chapter regarding inter-individual differences, we examined whether individual AB task performance could be related to differences in timing and investment of attention allocated to the targets as reflected in pupil dilation. We showed that individuals with a small AB timed their attention earlier relative to the onset of the targets, where in particular the timing to the second target seemed to be predictive for AB magnitude. This is in line with EEG studies, where it was found that the P3 component - associated with WM updating - peaked earlier for non-blinkers than for blinkers (Martens, Munneke, et al., 2006; Troche & Rammsayer, 2013). Furthermore, based on the suggestion that the AB might be due to overinvestment of attention to T1 (Taatgen et al., 2009), we

hypothesized that investment of attention to T1 would be higher in trials where T2 was reported incorrectly, i.e., blink trials, in comparison to trials where T2 was reported correctly, i.e., no-blink trials, and that this pattern would be most pronounced for large blinkers. However, in contrast to our expectations, we found this pattern only for small blinkers, and the exact opposite pattern for large blinkers. An explanation may be that evidence supporting the overinvestment hypothesis with regard to T1 processing is mostly found when comparing no-blink trials with blink trials (Maclean & Arnell, 2011; Martens, Munneke, et al., 2006; Wierda et al., 2012), whereas we studied the interaction between blink/no-blink trials and individual AB magnitude. Given that studies have also failed to relate P3 amplitude to individual AB magnitude (Martens, Elmallah, et al., 2006; McArthur et al., 1999; Wagner et al., 2015), further research is needed to clarify the relation between individual AB magnitude and investment of attention to T1 as reflected in neurophysiological measurements. Finally, in this chapter, we replicated our finding as described in the 3rd chapter of a positive relation between the number of order reversals and individual AB magnitude. This confirms the idea that a small AB magnitude is related to higher preservation of temporal information. However, it must be noted that in chapter 4, we presented evidence that at least part of the order reversals in a paradigm using alphanumerical stimuli—as we used here—may actually reflect integration of information in one temporal window, and thus, do not reflect 'true' order reversals.

TRAINING OF PERFORMANCE

In the second part of this thesis, I showed that AB task performance can be enhanced by training, but failed to find any training-induced changes by means of pupil dilation. In chapter 6, we replicated the result of an earlier study where the AB was resolved by training individuals with an RSVP task containing a color-salient T2 presented at a fixed short time interval from T1 (Choi et al., 2012). However, we revealed that the AB could already be attenuated by a training task without a color-salient target, but in which both targets were presented at a fixed short interval. Moreover, we showed that post-training performance only increased at the intervals participants were trained at, whereas performance decreased at the intervals that were not included in the training. These results are in line with earlier findings that suggest that the color-salient training effect was based on learning the temporal positions of the targets, i.e., on the creation of temporal expectancies (Tang et al., 2013). It remains unclear, though, how these results relate to other training methods known to enhance AB task performance, such as meditation or video gaming (Green & Bavelier, 2003; Slagter et al., 2007). However, it is evident that training can be beneficial for AB task performance, and thus, that a change in the applied attentional strategy can attenuate the AB. In addition to the behavioral data, we measured pupil dilation to reveal any attentional changes that might occur after performing the color-salient training task. However, we could not find any evidence for clear training-induced changes in attentional allocation related to changes in behavioral performance. It must be noted, though, that in the pupil dilation data, we did find that individual AB magnitude could predict

the timing of attentional allocation to T2. Given that we already showed evidence for the earlier timing of attention to the targets in chapter 5, these results confirm that the size of the blink is related to the timing of attention, particularly to the second target. In the current study, we did not find any evidence for earlier attention allocated to T1, which is in contrast to our findings in chapter 5. One explanation that findings with regard to T1 are less consistent may be that variability of timing on successful trials is likely to be higher for T1 than for T2.

Finally, in the 7th chapter, we showed that the AB can also be attenuated robustly by applying a non-RSVP target-mask training, where only a single letter target was presented that was dynamically masked by a digit. This increase in AB task performance was expected, because the color-salient training - as described in chapter 6 - was found to enhance performance in both the AB task and a target-mask task, thus, suggesting a relation between performance in these two tasks (Choi et al., 2012). This finding has implications for the temporal expectations theory mentioned earlier (Tang et al., 2013), because during the target-mask training task there was no possibility to build any temporal expectations of target positions. We hypothesized that the target-mask training teaches individuals to discriminate faster and/or more efficiently between relevant and irrelevant information. This would also be in line with the finding that action video gaming increases AB task performance, because here, it is also necessary to discriminate quickly between target information and distracting information (Green & Bavelier, 2003; Oei & Patterson, 2013). Furthermore, the fact that in the training task, difficulty to discriminate between the target and the mask was dynamically adapted to individual performance levels suggests that tailoring training to individual needs may be important to increase the effect of the training task (Reedijk et al., 2015). With regard to the pupil dilation measurements in the pre- and post-training task, there was again no evidence for any changes in attentional allocation as an effect of training. One hypothesis regarding our failure to show differences in attentional allocation between pre- and post-training sessions may be that the training influenced the ratio of blink/no-blink trials, i.e., fewer blink trials post-training than pre-training, but not the dynamics of attention within these trials.

CONCLUDING REMARKS

Following these chapters, it seems safe to conclude that studying the source of individ -ual differences in AB task performance has revealed important clues regarding the nature of the AB itself. First, in chapter 3, 4, and 5, we showed that AB magnitude relates positively to both order reversals in paradigms with alphanumeric stimuli, and temporal integration in a paradigm with symbol target stimuli. Therefore, I conclude that individuals with a smaller AB magnitude are better able to preserve temporal information regarding incoming visual events than individuals with a larger AB magnitude. Based on earlier studies on temporal integration, I presume that the latter is due to the use of a shorter temporal window to integrate incoming visual information. Bearing this in mind, it can also explain the patterns of delay, and the levels of precision of temporal selective attention as found in chapter 3. That is, the patterns of delay may well reflect the difficulty individuals have with identifying a target when it is presented near the

outer margin of the temporal window, thus, lag 1 for small blinkers and lag 3 for large blinkers. Furthermore, shorter temporal windows include less information, and thus result in less distractibility, i.e., higher levels of precision, regarding the temporal selection process of the target.

Second, based on the findings in the pupil dilation data as presented in chapter 5 and 6, it can be concluded that timing of attention allocated to the targets, and in particular to the second target, can predict AB magnitude, such that when individuals deploy attention earlier in time, they show higher AB task performance. Together with the temporal profile of individual AB differences as sketched in chapter 3, it can thus be concluded that a more precise and earlier timing of selective attention is beneficial for AB task performance.

Third, the results presented in chapter 6 and 7 indicate that performance in the AB task can be improved by various forms of training, although most of these training paradigms resulted in a reduction rather than a complete disappearance of the AB effect. Regarding the workings of the training, we presented evidence for the assumption that at least part of the color-salient training paradigm relies on the creation of temporal expectations regarding the timing of the targets. However, the finding that the AB can also be attenuated by a task that does not provide any temporal information regarding the targets, suggests that there is more to the story than just the creation of temporal expectations. The target-mask task may enhance the ability to discriminate between relevant and irrelevant information by improving precision and timing of attentional selection.

Taken together, the AB seems to be at least partly the result of applying a default attentional strategy that happens to be disadvantageous for performance in the AB paradigm, although this strategy may be optimal for performance in other contexts. The attentional strategy seems to be determined by multiple, interlinked factors, including executive working memory functioning, the scope of attentional focus, timing and precision of attention, and the size of the temporal integration window. These factors can be manipulated or trained such that the adapted attentional strategy is of better use in the AB paradigm. Future research should address the function of the default attentional strategy that is underlying the AB. If this strategy for example exists to optimize functioning in other situations, manipulations and training sessions that are beneficial for AB task performance could have repercussions for performance in other cognitive tasks. Answers to these and other remaining questions await further investigation in order to unravel the workings of the temporal selective attention system.

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SUPPLEMENTARY INFORMATION

Table 2.2 Summary of all papers that have been included for the review regarding individual differences in the AB..

TITLE AND AUTHORS (YEAR)	N*	TASK-SWITCH	T1/T2	DISTRACTOR STIMULI	PHYSIOLOGICAL MEASURE	EXTRA TASK**	STATISTICAL METHOD***
Relationships between attentional blink magnitude, RSVP target accuracy, and performance on other cognitive tasks, Arnell, Howe, Joanisse & Klein (2006)	64	No	Specific RAN elements: color, digit, letter or object picture	Similar stimuli as the targets	x	RAN (rapid automatized naming) task; Manual RT task; Delayed RT task; Vocal naming task; Location probe task	regression/ correlation
Executive control processes of working memory predict attentional blink magnitude over and above storage capacity, Arnell, Stokes, MacLean & Gicante (2010)	50	Yes	T1: Red letter; word; object picture, T2: Specific letter; word; object picture	Black letters; words; object pictures	x	Nelson-Danny reading test; Forward digit span; Backward digit span; OSPAN; Raven's Standard Progressive Matrices (SPM)	RM-ANOVA/ correlation
Attentional blink magnitude is predicted by the ability to keep irrelevant material out of working memory, Arnell & Stubitz (2010)	60	Yes	T1: White letter, T2: Black X	Black letters	x	Filtering efficiency task; WM capacity task	RM-ANOVA/ RM-ANCOVA
Failure of temporal selectivity: Electrophysiological evidence for (mis)selection of distractors during the attentional blink, Bourassa, Vachon & Brisson (2015)	24	No	Red letters	Black leters	EEG	x	RM-ANOVA/ correlation

Plasticity of visual attention in Isha yoga meditation practitioners before and after a 3-month retreat, Braboszcz, Cahn, Balakrishnan, Maturi, Grandchamp & Delorme (2013)	82	No	Digits	Letters	x	Stroop task; Global-local task	Wilcoxon ranksum test/ regression
Improved control of exogenous attention in action video game players, Cain, Prinzmetal, Shimamura & Landau (2014)	49	No	T1: White digit, T2: Black digit	Black letters	x	Anti-cuing task	GLMM
How does bilingualism improve executive control? A comparison of active and reactive inhibition mechanisms, Colzato, Bajo, Van den Wildenberg, Paolieri, Nieuwenhuis, La Heij & Hommel (2008)	36	No	Digits	Letters	x	Stop-signal; Inhibition of return	RM-ANOVA (monolinguals vs. bilinguals)
Religion and the attentional blink: Depth of faith predicts depth of the blink, Colzato, Hommel & Shapiro (2010)	40	No	Digits	Letters	x	x	RM-ANOVA (atheists vs. Calvinists)
Dopamine and the management of attentional resources: Genetic markers of striatal D2 dopamine predict individual differences in the attentional blink, Colzato, Slagter, De Rover & Hommel (2011)	157	No	Digits	Letters	Genotyping	x	RM-ANOVA/ regression
Blinks of the eye predict blinks of the mind, Colzato, Slagter, Spapé & Hommel (2008)	20	No	Digits	Letters	sEBR	x	RM-ANOVA (high vs. low sEBR))/correlation

Working memory and the attentional blink: Blink size is predicted by individual differences in operation span, Colzato, Spapé, Pannebakker & Hommel (2007)	80	No	Digits	Letters	x	OSPAN; Raven's SPM	RM-ANOVA/ RM-ANCOVA/ correlation/ regression
Individual differences in dispositional focus of attention predict attentional blink magnitude, Dale & Arnell (2010)	84	Yes	T1: White letter, T2: Black X	Letters	x	Global-local task	RM-ANOVA (high vs low local interference)/correlation
How reliable is the attentional blink? Examining the relationships within and between attentional blink tasks over time, Dale & Arnell (2013)	46	Yes; No	T1: Red letter, T2: Black X; Red letter	Black letters	x	x	RM-ANOVA/ correlation
Multiple measures of dispositional global/local bias predict attentional blink magnitude, Dale & Arnell (2014)	39; 49 ****	Yes; No	T1: Red letter, T2: Black X; Red letter	Black letters	x	Various global-local tasks	RM-ANOVA (high vs low global score)/ correlation/t-test
Individual differences within and across attentional blink tasks revisited, Dale, Dux & Arnell (2013)	118	Yes; No	Various	Various	x	x	RM-ANOVA/ correlation/ factor analysis
Distractor inhibition predicts individual differences in the attentional blink, Dux & Marois (2008)	48	No	T1: Red letter, T2: Green letter	White letters	x	x	RM-ANOVA/ correlation/t-test
From sensory processes to conscious perception, Feinstein, Stein, Castillo & Paulus (2004)	16	Yes	T1: String of odd or even numbers, T2: Neutral or aversive word	Strings of letters	fMRI	x	RM-ANOVA/ RM-ANCOVA (blinkers vs. non-blinkers)

The DRD2 C957T polymorphism and the attentional blink – A genetic association study, Felten, Montag, Kranczioch, Markett, Walter & Reuter (2013)	211	Yes	T1: Green letter, T2: Black X	Black digits	Genotyping	x	RM-ANCOVA
Developmental aspects of temporal and spatial visual attention: Insights from the attentional blink and visual search tasks, Garrad-Cole, Shapiro & Thierry (2010)	64; 16	No	Blue isosceles triangles pointing left/ right or red isosceles triangles pointing up/down	Random colored shapes	x	Visual search task	RM-ANOVA (groups based on age)
Progressive age-related changes in the attentional blink paradigm, Georgiou-Karistianis, Tang, Vardy, Sheppard, Evans, Wilson, Gardner, Farrow & Bradshaw (2007)	50	No	Red letters	Black letters	x	National adult reading test; Beck depression inventory II	RM-ANOVA (groups based on age)/correlation
Action video game modifies visual selective attention, Green & Bavelier (2003)	16; 17	Yes	T1: White letter, T2: Black X	Black letters	x	Flanker task; Enumeration task; Useful field of view task	RM-ANOVA (video game players vs. non video game players)
Tracking the attentional blink profile: A cross-sectional study from childhood to adolescence, Heim, Benasich, Wirth & Keil (2013)	204	No	T1: Green sketches of transport means, T2: Green geometric shapes	White geometric figures and shapes	x	x	RM-ANOVA (groups based on grade)
Competition for cognitive resources during rapid serial processing: Changes across childhood, Heim, Wirth & Keil (2011)	45	No	Green symbols; letters	White symbols; letters	x	Raven's SPM; Digit span subtest (WISC III)	RM-ANOVA (young vs. old)/ correlation
Effect of tobacco deprivation on the attentional blink in rapid serial visual presentation, Heinz, Waters, Taylor, Myers, Moolchan & Heishman (2007)	90	No	Red neutral words	Black neutral words	x	x	RM-ANOVA (smokers vs. deprived smokers vs. non-smokers)

Effect of cognitive aging on working memory consolidation, Jain & Kar (2014)	45	No	Letters	Digits; up/down arrow	x	MMSE; Rey's auditory verbal learning test; Logical memory test; Rey's complex figure test; Wisconsin card sorting test; Perceptual load task	RM-ANOVA (groups based on age)
No commonality between attentional capture and attentional blink, Kawahara & Kihara (2011)	135; 95	No	T1: Digit, T2: Digit; Digit outside central RSVP	Letters	x	Temporal and spatial visual search tasks	RM-ANOVA/ correlation
Different attentional blink tasks reflect distinct information processing limitations: An individual differences approach, Kelly & Dux (2011)	39; 37	Yes; No	Various	Various	x	x	RM-ANOVA/t-test/correlation
Bilingualism and the increased attentional blink effect: Evidence that the difference between bilinguals and monolinguals generalizes to different levels of second language proficiency, Khare, Verma, Kar, Srinivasan & Brysbaert (2013)	132	Yes	T1: White letter, T2: Black X	Black letters	x	LexTALE test of L2 proficiency; Raven's SPM; language background questionnaire	RM-ANOVA (high vs. low second language proficiency)/ correlation
Individuals differ in the attentional blink: Mental speed and intra-subject stability matter, Klein, Arend, Beauducel & Shapiro (2011)	78; 58	No	T1: Red letter, T2: Blue letter	Black letters	x	Sternberg's memory search paradigm; N-back task; Predictive flexibility; Reactive flexibility; Pro- and anti-saccades; Psychometric intelligence; Span of apprehension task; Inspection time task; Visual search task	RM-ANOVA/ correlation/ principcal component analysis
Simultaneous and preceding sounds enhance rapid visual targets: Evidence from the attentional blink, Kranczioch & Thorne (2013)	21	No	Letters	Meaningless shapes; masks: patterned squares	x	Cognitive failures questionnaire; NEO Fünf Faktoren Inventar; Test of attentional performance	RM-ANOVA/ correlation
Age differences in the magnitude of the attentional blink, Lahar, Isaak & McArthur (2001)	55	Yes	T1: White target letter, T2: Red probe	Black target letters	x	Horn vocabulary test; Simple word span measures; Loaded word span measures	RM-ANOVA (young vs. old)

Attentional blink in adolescents with varying levels of impulsivity, Li, Chen, Lin & Yang (2005)	69	Yes	T1: Digit, T2: X-like character	Chinese characters	x	Barrat Impulsiveness Scale version 11; Maudsley obsessive compulsive inventory; Buss-perry aggression questionnaire; Children's depression inventory	RM-ANOVA (low vs. intermediate vs. high impulsivity)
Cognitive and attentional changes with age: evidence from attentional blink deficits, Maciokas & Crognale (2002)	32; 20	No	Letters	Digits	x	x	RM-ANOVA (young vs. old)
Personality predicts temporal attention costs in the attentional blink paradigm, MacLean & Arnell (2010)	29	No	T1: 5 repeated white uppercase or lowercase letters, T2: color word	Non-color neutral words	x	NEO personality inventory-revised; Emotion report form	t-test/regression/correlation
Individual differences in electrophysiological responses to performance feedback predict AB magnitude, MacLean & Arnell (2013)	67	Yes	T1: White letter, T2: Black X	Black letters	EEG	Time production task; Flanker task	t-test/ RM-ANOVA/ correlation
Dispositional affect predicts temporal attention costs in the attentional blink paradigm, MacLean, Arnell & Busseri (2010)	68	Yes	T1: Red letter; word; object picture, T2: Specified letter; word; object picture	Letters; words; object pictures	x	PANAS	RM-ANOVA/ correlation/ regression
Resting EEG in alpha and beta bands predicts individual differences in attentional blink magnitude, MacLean, Arnell & Cote (2012)	30; 38	Yes	T1: 5 repeated white uppercase or lowercase letters; white letter, T2: color word; black X	Non-color neutral words; black letters	EEG	x	t-test/ RM-ANOVA/ correlation
Aging extents the time required to switch cognitive set, Male, Sheppard & Bradshaw (2009)	25	Yes	T1: Colored square, T2: Colored letter	Black letters	x	Kaufman brief intelligence test	RM-ANOVA/ RM-ANCOVA (young vs. old)

A quick mind with letters can be a slow mind with natural scenes: Individual differences in attentional selection, Martens, Dun, Wyble, & Potter (2010)	29	No	Letters; Superordinate category pictures	Digits; Pictures of natural scenes	x	x	RM-ANOVA (blinkers vs. non-blinkers)
Cuing and stimulus probability effects on the P3 and the AB, Martens, Elmallah, London & Johnson (2006)	24; 17	No	T1: Frequent or infrequent letter; correctly cued or incorrectly cued letter, T2: Letter	Digits	EEG	x	RM-ANOVA/ correlation
Working memory capacity, intelligence, and the magnitude of the attentional blink revisited, Martens & Johnson (2009)	97	No	Letters	Digits	x	Symmetry span test; Reading span test; Matrix span test; Letter span test; Raven's APM	RM-ANOVA/ RM-ANCOVA/ correlation/ regression
A quick visual mind can be a slow auditory mind: Individual differences in attentional selection across modalities, Martens, Johnson, Bolle & Borst (2009)	27	No	Letters; spoken letters	Digits; spoken digits	x	x	RM-ANOVA (blinkers vs. non-blinkers)
Restricted attentional capacity within but not between sensory modalities: An individual differences approach, Martens, Kandula & Duncan (2010)	56	No	Letters; spoken letters	Digits; spoken digits	x	x	RM-ANOVA/ correlation
Quick minds slowed down: Effects of rotation and stimulus category on the attentional blink, Martens, Korucuoglu, Smid & Nieuwenstein (2010)	24; 24; 19	No	Letters (normal; rotated)	Digits (normal; rotated); letters (normal; rotated)	EEG	x	RM-ANOVA (blinkers vs. non-blinkers)

Quick minds don't blink: Electrophysiological correlates of individual differences in attentional selection, Martens, Munneke, Smid & Johnson (2006)	22; 22	No	Letters	Digits	EEG	x	RM-ANOVA (blinkers vs. non-blinkers); correlation
Individual differences in the attentional blink: The important role of irrelevant information, Martens & Valchev (2009)	28	No	Letters	Digits	x	Target-mask, target-mask task	RM-ANOVA (blinkers vs. non-blinkers)/ t-test
Musical minds: Attentional blink reveals modality-specific restrictions, Martens, Wierda, Dun, De Vries & Smid (2015)	48	No	Spoken letters; letters	Spoken digits; digits	x	x	GLMM (musicians vs. non-musicians)/correlation
The attentional blink and P300, McArthur, Budd & Michie (1999)	14; 12	Yes	T1: White letter, T2: Black X	Black letters	EEG	x	RM-ANOVA/ correlation
The attentional blink is immune to masking-induced data limits, McLaughlin, Shore & Klein (2001)	16	No	Letters	Digits	x	Target-mask, target-mask task	RM-ANOVA/ correlation
The attentional blink in developing readers, McLean, Stuart, Visser & Castles (2009)	86	No	1 out of 5 shapes	Keyboard symbols & random dot patches	x	Three reading measures; Non-verbal IQ; RAN	RM-ANOVA/ correlation/ regression
Eliminating the attentional blink through binaural beats: A case for tailored cognitive enhancement, Reedijk, Bolders, Colzato & Hommel (2015)	24	No	Digits	Letters	sEBR	x	RM-ANOVA (low vs. high EBR)
Resource sharing in the attentional blink, Shapiro, Schmitz, Martens, Hommel & Schnitzler (2006)	10	No	X/O; L/T	White letters	MEG	x	RM-ANOVA/ correlation

Using the attention cascade model to probe cognitive aging, Shih (2009)	42	No	Digits	Letters	x	x	RM-ANOVA (young vs. old)
Distractor inhibition predicts individual differences in recovery from the attentional blink, Slagter & Georgopoulou (2013)	40	No	T1: Red letter, T2: Green letter	White upper-case letters	sEBR	x	RM-ANOVA/ correlation
Neural competition for conscious representation across time: An fMRI study, Slagter, Johnstone, Beets & Davidson (2010)	16; 24	No	T1: Body without a head, T2: Natural scene	Scrambled scene images	fMRI	x	RM-ANOVA/t-test
Mental training affects distribution of limited brain resources, Slagter, Lutz, Greischar, Francis, Nieuwenhuis, Davis, Davidson (2007)	40	No	Digits	Letters	EEG	x	RM-ANOVA/ RM-ANCOVA (novices vs. practitioners)/ correlation
Theta phase synchrony and conscious target perception: Impact of intensive mental training, Slagter, Lutz, Greischar, Nieuwenhuis & Davidson (2009)	40	No	Digits	Letters	EEG	x	RM-ANOVA (novices vs. practitioners)/ Wilcoxon sign rank test
PET evidence for a role for striatal dopamine in the attentional blink: Functional implications, Slagter, Tomer, Christian, Fox, Colzato, King, Murali & Davidson (2012)	14	No	Digits	Letters	PET	x	RM-ANOVA/ correlation
The more your mind wanders, the smaller your attentional blink: An individual differences study, Thomson, Ralph, Besner & Smilek (2014)	121; 102	No	Letters	Digits	x	Sustained attention to response task; Mind wandering spontaneous and deliberate questionnaires	RM-ANOVA/ correlation

Evidence for mental ability related individual differences in the attentional blink obtained by an analysis of the P300 component, Troche, Indermühle & Rammsayer (2012)	60	Yes	T1: Yellow letter, T2: Digit "2"	White letters	EEG	Berlin intelligence structure test	RM-ANOVA (high vs. low mental ability)
Attentional blink and impulsiveness: Evidence for higher functional impulsivity in non-blinkers compared to blinkers, Troche & Rammsayer (2013)	30	Yes	T1: Yellow letter, T2: Digit "2"	White letters	EEG	Dickman's impulsivity inventory	RM-ANOVA/t-test (blinkers vs. non-blinkers)
Age effects on attentional blink performance in meditation, Van Leeuwen, Müller & Melloni (2009)	51	Yes	T1: Red digit, T2: Black digit	Letters	x	x	RM-ANOVA (groups based on age and meditation experience)
Control over experience? Magnitude of the attentional blink depends on meditative state, Van Vugt & Slagter (2014)	30	No	Digits	Letters	x	Five factor mindfulness Questionnaire; questionnaire meditation experience; Beck Depression Inventory; PANAS; State-trait anxiety inventory-trait	RM-ANOVA (FA meditation vs. OM meditation)
How does information processing speed relate to the attentional blink?, Visser & Ohan (2012)	69	No	Letters	Random dot patches & digits & keyboard symbols	x	Rapid letter naming test (RAN)	RM-ANOVA (low RAN score vs. high RAN score)/ correlation
Relations between the attentional blink and aspects of psychometric intelligence: A fixed-links modeling approach, Wagner, Rammsayer, Schweizer & Troche (2014)	201	Yes	T1: Yellow letter, T2: Digit "2"	White letters	x	Berlin intelligence structure test	RM-ANOVA/ fixed-links modeling

A fixed-links modeling approach to assess individual differences in the attentional blink: Analysis of behavioral and psychophysiological data, Wagner, Rammsayer, Schweizer & Troche (2015)	201	Yes	T1: Yellow letter, T2: Digit "2"	White letters	EEG	x	RM-ANOVA/ fixed-links modeling
Individual differences in the attentional blink: The temporal profile of blinkers and non-blinkers, Willems, Wierda, Van Viegen & Martens (2013)	28; 132	No	Red letters	Black letters	x	x	RM-ANOVA/ RM-ANCOVA (Experiment 1: blinkers vs. non-blinkers)
Aerobic fitness and the attentional blink in pre-adolescent children, Wu & Hillman (2013)	39	No	White digits	White letters	EEG	Kaufman brief intelligence test; Eidenburgh handedness inventory; Cardiorespiratory fitness assessment	RM-ANOVA (high-fit vs. low-fit children)

* The reported N is the sample size after exclusion of any participants

** The extra tasks were either tested within the same sample of participants as tested in the AB task, or in a (partially) different sample

*** Only the main statistical methods that are used per study are mentioned, so for example post-hoc tests are omitted. If the sample was somehow grouped, this is indicated within parentheses. **Note:** RM-ANOVA – Repeated Measures Analysis of Variance; RM-ANCOVA – Repeated Measures Analysis of Covariance - GLMM – Generalized Linear Mixed Model

**** Multiple numbers divided by ";" refers to multiple experiments

Table 6.2A. Results omnibus GLMM behavioral results with the color-salient condition as reference category

FACTOR	β	SE	Z-VALUE	P-VALUE
Intercept	2.01	.20	10.11	< .001***
Lag[1]	-1.12	.14	-8.00	< .001***
Session [2]	-.43	.15	-2.90	.004**
Lag-2 Condition[3]	-.18	.27	-.66	.510
Lag-2&6 Condition[3]	-.19	.28	-.66	.510
Lag x Session	.86	.19	4.46	< .001***
Lag x Lag-2 Condition	-.11	.19	-.57	.567
Lag x Lag-2&6Condition	.09	.19	.48	.632
Session x Lag-2 Condition	.03	.20	.14	.891
Session x Lag-2&6 Condition	.91	.22	4.25	< .001***
Lag x Session x Lag-2 Condition	-.05	.26	-.18	.856
Lag x Session x Lag-2&6 Condition	-1.10	.28	-3.96	< .001***

Significance codes: '***' < .001, '**' < .01, '*' < .05

[1] Reference category is "lag 6"

[2] Reference category is "pre-training session"

[3] Reference category is "Color-Salient condition"

Table 6.2B. Results omnibus GLMM behavioral results with the lag-2 condition as reference category

FACTOR	β	SE	Z-VALUE	P-VALUE
Intercept	1.83	.18	9.91	< .001***
Lag[1]	-1.22	.13	-9.78	< .001***
Session [2]	-.40	.13	-3.03	.003**
Lag-2 Condition[3]	.18	.27	.66	.510
Lag-2&6 Condition[3]	-.01	.27	-.02	.982
Lag x Session	.82	.17	4.71	< .001***
Lag x Lag-2 Condition	.11	.19	.57	.567
Lag x Lag-2&6Condition	.20	.18	1.10	.274
Session x Lag-2 Condition	-.03	.20	-.14	.891
Session x Lag-2&6 Condition	.89	.21	4.33	< .001***
Lag x Session x Lag-2 Condition	.05	.26	.18	.856
Lag x Session x Lag-2&6 Condition	-1.05	.26	-3.99	< .001***

Significance codes: '***' < .001, '**' < .01, '*' < .05

[1] Reference category is "lag 6"

[2] Reference category is "pre-training session"

[3] Reference category is "Lag-2 condition"

Table 6.2C. Results omnibus GLMM behavioral results with the lag-2&6 condition as reference category

FACTOR	β	SE	Z-VALUE	P-VALUE
Intercept	1.82	.20	9.40	< .001***
Lag[1]	-1.02	.13	-7.73	< .001***
Session [2]	.49	.16	3.11	.002**
Color-Salient Condition[3]	.19	.28	.66	.510
Lag-2 Condition[3]	.01	.27	.02	.982
Lag x Session	-.23	.20	-1.17	.241
Lag x Color-Salient Condition	-.09	.19	-.48	.632
Lag x Lag-2 Condition	-.20	.18	-1.10	.274
Session x Color-Salient Condition	-.92	.21	-4.25	< .001***
Session x Lag-2 Condition	-.89	.21	-4.33	< .001***
Lag x Session x Color-Salient Condition	1.10	.28	3.95	< .001***
Lag x Session x Lag-2 Condition	1.05	.26	3.99	< .001***

Significance codes: '***' < .001, '**' < .01, '*' < .05

[1] Reference category is "lag 6"

[2] Reference category is "pre-training session"

[3] Reference category is "Lag-2&6 condition"

INDIVIDUELE VERSCHILLEN IN AANDACHT IN TIJD

Elk moment van de dag wordt ons visuele systeem belaagd met grote hoeveelheden informatie. Met behulp van ons aandachtsysteem maken wij echter, schijnbaar moeiteloos, doorlopend onderscheid tussen informatie die op dat moment relevant voor ons is en informatie die niet van belang is. Zo goed als mogelijk wordt relevante informatie verwerkt tot op bewustzijnsniveau, terwijl irrelevante informatie grotendeels wordt verworpen zodra het niet langer nodig is. Dit houdt dus in dat praktisch alle informatie waar we ons uiteindelijk bewust van worden, is geselecteerd aan de hand van ons aandachtsysteem in ruimte of tijd. In het geval van selectie van informatie in tijd spreken we over temporele selectieve aandacht en in dit proefschrift onderzoek ik hoe dit temporele selectieve aandachtsysteem werkt.

Om de werking van temporele selectieve aandacht te onderzoeken, wordt het attentional blink paradigma gebruikt (Raymond et al., 1992). In dit paradigma wordt in het midden van een computerscherm een sequentiële stroom van visuele stimuli getoond met een snelheid van ongeveer 10 stimuli per seconde. Doorgaans bestaat deze stroom uit twee target stimuli die geïdentificeerd moeten worden (bijvoorbeeld twee letters) ingebed in meerdere distractor stimuli (bijvoorbeeld cijfers). Als de stroom eindigt, worden deelnemers gevraagd om aan te geven welke twee target stimuli zij gezien hebben. Over het algemeen is deze rapportage geen probleem voor de eerste target (T1), maar rapportage van de tweede target (T2) gaat vaak fout als T2 te snel na T1 wordt gepresenteerd (binnen 200-500 ms). Als T2 echter direct na T1 of na een langere tijdsperiode na T1 wordt gepresenteerd, is identificatie van T2 vaak wel succesvol. Verder is het waarnemen van T2 ook geen probleem als deelnemers worden geïnstrueerd om T1 te negeren, wat aangeeft dat het missen van T2 toegeschreven kan worden aan aandachtrestricties in plaats van aan beperkte perceptie. Naar analogie met het knipperen van de ogen, wordt deze korte periode waarin het moeilijk is om T2 na T1 waar te nemen de “attentional blink” genoemd (AB).

INDIVIDUELE VERSCHILLEN

Onderzoek naar de oorzaak van de AB kan ons meer vertellen over hoe het temporele selectieve aandachtsysteem werkt. Eén manier om dit te bestuderen is door te onderzoeken hoe en waarom individuen verschillend presteren op de AB taak. Ondanks dat de AB een robuust en universeel fenomeen is, laten mensen namelijk sterk verschillende prestatieniveaus zien op de AB taak (Dale & Arnell, 2013; Dale et al., 2013). Het onderzoeken van deze individuele verschil-

len binnen een groep kan naast het onderzoeken van groepsgemiddelden een gedetailleerder beeld schetsen van temporele selectieve aandacht. Om in kaart te brengen wat tot nu toe al bekend is over individuele verschillen in AB taakprestatie hebben wij in hoofdstuk 2 een review opgesteld van de literatuur in dit veld zoals gepubliceerd tot augustus 2015. Hier laten we zien dat de grootte van de aandachtfocus en het executief werkgeheugen gezien kunnen worden als voorspellers van AB taakprestatie.

In hoofdstuk 3 gaan we verder in op individuele verschillen in AB taakprestatie door het bestuderen van drie dimensies van temporele selectieve aandacht, namelijk suppressie, vertraging en diffusie (Vul et al., 2008). Door het analyseren van foutieve targetrapportages onderzochten wij in hoeverre individuen verschillen in de mate dat ze distractor stimuli onderdrukken (suppressie) en in de mate dat aandacht in tijd vertraagd (vertraging) of verspreid (diffusie) wordt toegewezen. Ook bestudeerden we individuele verschillen in de mate waarin T1 en T2 correct maar in omgekeerde volgorde werden gerapporteerd. Verrassend genoeg vonden we weinig bewijs voor onderdrukking van distractors, maar individuen die goed presteerden op de AB taak hadden wel een minder verspreid antwoordpatroon en waren dus preciezer in hun selectieproces. Als ze fouten maakten, selecteerden ze vaak distractoren die slechts kort voor of na de target gepresenteerd waren. Bovendien rapporteerden individuen met een goede taakprestatie de targets minder vaak in omgekeerde volgorde dan individuen die minder goed presteerden. In hoofdstuk 4 verdiepen we ons onderzoek naar deze omgekeerde targetrapportages, die aangeven dat de tijdsinformatie van binnenkomende informatie niet correct is verwerkt. Tevens laten we zien dat personen die minder goed presteren op de AB taak vaker geneigd zijn om twee visuele stimuli te integreren tot één visueel beeld. Bijvoorbeeld: / en \ kunnen worden geïntegreerd tot X. Op basis hiervan nemen we aan dat individuen die goed presteren gebruik maken van een kleiner zogenaamd temporeel integratie venster om binnenkomende informatie te verwerken dan individuen die minder goed presteren op de AB taak. Dat wil zeggen dat mensen die goed presteren de stroom van binnenkomende informatie in kleinere stukken verdelen en verwerken. Hierdoor zijn ze beter in het bewaren van de tijdsvolgorde van deze informatie dan mensen die minder goed presteren en grotere temporele vensters gebruiken.

PUPIL DILATATIE

Om de timing van aandacht en de hoeveelheid aandacht te meten tijdens de AB taak hebben we pupil dilatatie gemeten. De verwijding van de pupil laat namelijk zien hoeveel en wanneer aandacht wordt gebruikt (Hess & Polt, 1960; Hoeks & Levelt, 1993; Kahneman & Beatty, 1966). Maar omdat de reactie van de pupil relatief langzaam is, namelijk ongeveer 1 seconde, resulteren de pupilresponsen op de stimuli in de AB taak in overlappende signalen, aangezien er in de AB taak ongeveer 10 stimuli per seconde worden gepresenteerd. Maar door gebruik te maken van de karakteristieke manier waarop de pupil op een willekeurige stimulus reageert, kunnen deze overlappende pupilresponsen uit elkaar worden gehaald met de zogenaamde pupil dilatatie deconvolutie analyse methode (Wierda et al., 2012) en kunnen de target-specifieke pupilresponsen worden achterhaald. Op deze manier kan dus berekend worden wanneer en

hoeveel aandacht is toegewezen aan de targets in de AB stroom. Met behulp van deze deconvolutie methode, bestudeerden we in hoofdstuk 5 of individuele verschillen in AB taakprestatie gekoppeld kunnen worden aan verschillen in timing en hoeveelheid van aandacht toegewezen aan de targets. Hier vonden we onder andere dat individuen die beter zijn in de AB taak eerder hun aandacht kunnen richten op de targets dan individuen met lagere prestaties.

TRAINING

In de eerste twintig jaar dat er onderzoek werd gedaan naar de AB werd er aangenomen dat AB taakprestatie wel enigszins verbeterd kon worden, bijvoorbeeld door het spelen van videogames of het uitoefenen van meditatie (Green & Bavelier, 2003; Slagter et al., 2007), maar dat de AB niet of nauwelijks kleiner werd als men de AB taak vaak zou herhalen (Braun, 1998; Taatgen et al., 2009). Onlangs is echter aangetoond dat de AB weg getraind kan worden door een korte, specifieke training. Tijdens deze training maakte men gebruik van een AB taak waarbij T2 rood gekleurd was en de targets altijd met hetzelfde tijdsinterval werden gepresenteerd (Choi et al., 2012). Als vervolgens de reguliere AB taak weer werd uitgevoerd, was het verwerken van beide targets niet langer een probleem. In hoofdstuk 6 repliceerden we het effect van deze training, maar vonden we geen duidelijke verschillen in timing en hoeveelheid van toegewezen aandacht aan de hand van pupil dilatatie metingen tussen pre- en post-training. Wel vonden we dat mensen ook getraind kunnen worden door middel van een taak waarbij geen gekleurde T2 aanwezig is, maar waar alleen T1 en T2 op een vast tijdsinterval worden getoond. Dit ondersteunt eerdere bevindingen dat het effect van de training wellicht gebaseerd is op het leren van het tijdsinterval en niet zozeer op een fundamentele verandering in het aandachtssysteem. In hoofdstuk 7 laten we verder zien dat AB taakprestatie ook getraind kan worden aan de hand van een taak die helemaal niet lijkt op de originele AB taak. In deze nieuwe training krijgen mensen namelijk maar één target te zien die heel snel wordt gevolgd door een enkele distractor. De presentatieduur van deze target en distractor samen was altijd even lang, maar hoe beter een persoon presteerde des te korter werd de presentatieduur van de target en des te langer werd de duur van de distractor. Op deze manier werden mensen uitgedaagd om steeds op de toppen van hun kunnen te presteren. AB taakprestatie verbeterde na deze zogenaamde target-mask training en bovendien was dit effect nog steeds aanwezig toen mensen na een maand nogmaals werden getest. Verder hebben we ook hier pupil dilatatie gemeten, maar vonden we weer geen duidelijke verschillen tussen pre- en post-training pupil dilatatie.

CONCLUSIE

Deze bevindingen laten zien dat het bestuderen van individuele verschillen in AB taakprestatie belangrijke aanwijzingen aan het licht kan brengen aangaande de oorzaak van de AB en dus de werking van temporele selectieve aandacht. In dit proefschrift hebben we laten zien dat mensen die beter presteren op de AB taak ook beter in staat zijn om tijdsinformatie van binnenkomende visuele informatie te bewaren dan mensen die minder goed presteren. Op basis van onze bevindingen nemen we aan dat mensen met een hogere taakprestatie gebruik maken van kortere temporele vensters om informatie te verwerken. Verder hebben we gevonden dat

de timing en precisie van aandacht naar de targets als voorspeller kan worden gezien van AB taak prestatie. Dus hoe eerder iemand in staat is om zijn aandacht naar de target toe te sturen, hoe beter de prestatie op de AB taak. Als laatste laten we in dit proefschrift zien dat prestatie op de AB taak verbeterd kan worden door middel van verschillende specifieke trainingen. We concluderen dat de training met de gekleurde T2 in ieder geval gedeeltelijk gebaseerd is op het leren van het tijdsinterval tussen de targets, al laten we in hoofdstuk 7 zien dat prestatie in de AB taak ook getraind kan worden met een taak die geen temporele informatie bevat omtrent de presentatie van de targets. Deze target-mask taak verhoogt wellicht het vermogen om onderscheid te maken tussen relevante en irrelevante informatie door het aanscherpen van precisie en timing van aandachtselectie.

Bij elkaar genomen lijkt de AB in ieder geval gedeeltelijk te worden veroorzaakt door het standaard toepassen van een strategie van het temporele selectieve aandachtsysteem die in de meeste omstandigheden wellicht goed werkt, maar nadelig uitpakt voor AB taakprestatie. De strategie lijkt te bestaan uit meerdere, samenhangende factoren, inclusief het functioneren van het executief werkgeheugen, de spanwijdte van de aandachtfocus, timing en precisie van aandacht en de grootte van het temporele integratie venster. Deze factoren kunnen worden gemanipuleerd of getraind zodat de aangepaste aandachtstrategie beter van toepassing is op de AB taak. Toekomstig onderzoek zal moeten uitwijzen wat de eventuele praktische functie van een dergelijke strategie kan zijn.

BEDANKT!

Natuurlijk had ik dit proefschrift nooit kunnen schrijven zonder de hulp en steun van anderen. Allereerst dank aan mijn co-promotor, **SANDER MARTENS**. Bedankt voor je steun en kennis de afgelopen drie jaar, je vertrouwen in mijn kunnen en je feedback hierop. Ook alle dank aan mijn promotor, **ANDRE ALEMAN**. Ook al hadden we pas in het laatste jaar wat regelmatiger contact, jouw feedback heeft ervoor gezorgd dat ook de finesses van dit proefschrift goed in elkaar zitten. **ATSER** en **STEFAN**, zonder jullie ideeën, suggesties en wijsheid was ik niet gekomen waar ik nu ben. Jullie hebben geholpen dit werk naar een hoger niveau te tillen. Echter wil ik jullie ook bedanken voor de mentale ondersteuning en de goede gesprekken tijdens lunch of koffie. Of het nou ging over mixed models, vrije wil of de nieuwste Homeland of Breaking Bad, jullie bijdrages waren altijd interessant. En natuurlijk dank dat jullie mijn paranimfen willen zijn.

Ook wil ik alle verdere co-auteurs bedanken. **NIELS. EVA. JEFTA** en **ELKAN**, bedankt voor een goede samenwerking en jullie feedback en ideeën. Het is altijd fijn als iemand een frisse blik op je werk werpt. **JOHANNES** en **JANNE**, bedankt dat jullie je scriptie bij ons wilden schrijven en bedankt voor jullie inzet hierbij. Hiernaast wil ik graag **JELMER** en **TRUDY** bedanken. Na een meeting met jullie en met Niels zat ik altijd weer vol nieuwe ideeën. Bedankt voor deze constructieve samenwerking. Ook wil ik graag **MARK NIEUWENSTEIN** bedanken. Mark, zonder jouw aanstekelijke enthousiasme tijdens mijn studie was ik waarschijnlijk nooit in de wetenschap terecht gekomen. Bedankt voor deze inspiratie.

ELOUISE. MIRJAN en **SANDRA.** mede crazy cat ladies van kamer 124, bedankt voor de gezelligheid, de grapjes en de vele kopjes thee samen, maar ook voor het klankbord zijn als het PhD-leven even niet zo soepel ging. **HELEEN**, ook jou wil ik bedanken voor de gezelligheid, je aanstekelijke ambitie en energie, maar natuurlijk ook voor het mij altijd meeslepen naar de ACLO. Verder dank aan alle andere collega's op het NIC voor de open sfeer, de mogelijkheid om hulp te vragen waar nodig en de praatjes bij de koffie automaat waar altijd interesse in de ander uit naar voren kwam.

De laatste anderhalf jaar van mijn project was nooit zo inspirerend, leuk en druk geweest zonder dat ik had deelgenomen aan de organisatie van het GSMS PhD Development Congres. **NICOLE. TUSHAR. DARIO. ENA. MIRJAN. HELEEN** en **STEFAN**, jullie wil ik graag bedanken voor een ontzettende leuke tijd waar ik veel heb geleerd. Jullie inzet en professionaliteit was bewonderingswaardig en het was heel tof om uiteindelijk samen zo'n geslaagd congres neer te zetten. Ook dank aan GSMS dat jullie ons deze mogelijkheid hebben gegeven.

BEDANKT!

Uiteindelijk ook dank aan mijn familie en vrienden. **PAPA. MAMA. CLAUDIA. BAS** en **RITGER.** jullie zijn het leukste gezin van de wereld. **OPA** en **OMA**, ik had me geen lievere opa en oma kunnen wensen. Ook de rest van mijn familie, waar ook mijn schoonfamilie natuurlijk toebehoort, bedankt voor jullie nooit aflatende interesse en jullie gezelligheid. **WENDA**, jouw doorzettingsvermogen, halloumi burgers en onze wekelijkse etentjes zijn geweldig. Bedankt! **YVONNE.** ik zie ons nog zitten als dertienjarige meisjes met kort roze haar, M&Ms etend in het bushokje, bedankt voor alles vanaf toen. Mijn liefste roeiploeg, **ANNE. MAARTJE. GEPKE. ANNEMARIE. RENÉE** en **FENNE.** bedankt voor jullie grapjes en jullie nuchtere kijk op de wereld. **ABEL.** jij bedankt voor je pluizige aanwezigheid. Je bent de beste kat van de wereld. Als laatste dank aan mijn allerliefste, **MARTIJN**. Zonder jou zou ik niets en nergens zijn. Ik hou van jou.